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TV Station Film Operation

Stereoscopic Photography

Optical Techniques for Flow

Conversion of 16mm Printers

Carbon-Arc Light Source

Carbons in the Blown Arc

Brightness of Motion-Picture Screens

American Standards

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Increasing the Efficiency of Television Station Film Operation . . . . R. A. Isberg 447

A Mathematical and Experimental Foundation for Stereoscopic Photography . . . . . Armin J. Hill 461

Optical Techniques for Fluid Flow . . . . . Norman F. Barnes 487

Conversion of 16mm Single-Head Continuous Printers for Simultaneous Printing of Picture and Sound on Single-System Negative . . . . . Victor E. Patterson 512

An Improved Carbon-Arc Light Source for Three-Dimensional and Wide-Screen Projection . . . . . Edgar Gretener 516

Performance of High-Intensity Carbons in the Blown Arc . . . . . C. E. Greider 525

Specifying and Measuring the Brightness of Motion-Picture Screens . . F. J. Kolb, Jr. 533

American Standards 557
Proposed, Aperture for 35mm Sound Motion-Picture Projectors (Second Draft), PH22.58; Proposed, Aperture for 35mm Sound Motion-Picture Cameras (First Draft), PH22.59.

Engineering Activities 560

Book Reviews 560
Principles of Color Photography, by Ralph M. Evans, W. T. Hanson, Jr., and W. Lyle Brewer, reviewed by Lloyd E. Varden; *New Screen Techniques*, edited by Martin Quigley, Jr., reviewed by Arnold F. T. Kotis; *Television Advertising and Production Handbook*, by Irving Settle, Norman Glenn and Associates, reviewed by William K. Aughenbaugh; *1953–54 Motion Picture and Television Almanac*, a Quigley Publication.

New Members 563

Employment Service 566

Meetings 566

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Increasing the Efficiency of Television Station Film Operation

By R. A. ISBERG

Techniques have been developed in the scheduling of film programs and the splicing of films which reduce the technical manpower required for operations. By utilizing oversize reels and remote control of the projection equipment, two men can easily handle audio and video control and also be responsible for normally unattended film projection equipment. Practical techniques of film splicing and editing are also described.

More than half of the average television station's program time is generally supplied by 16mm film. Film is required from sign-on to sign-off time which covers a period of from ten to seventeen hours per day. During major portions of the program schedule the entire operation usually depends upon film with no live studio participation. In some of the smaller stations the entire program schedule is transmitted from film and network microwave, if available.

From the standpoint of economy, it is desirable to have the studio, offices and transmitter at one location, but in many areas propagation considerations require that the transmitter be located on a high hill or mountain. This almost invariably results in separate studio and transmitter locations with a correspondingly increased technical staff.

After careful consideration of operating costs and program plans, some television stations have installed their film-projection facilities at their transmitter and their live studio facilities at a downtown location. This permits film operation at any time and live telecasting can be confined to times when a studio crew is available. However, it creates a minor film-transportation and make-up problem, and in some ways complicates the integration of film with live programs, since the film-camera monitors cannot be economically duplicated at the studio. This latter objection applies particularly to the preview of visual effects by the producer or director at the studio prior to their use in an integrated live and film program, but it is possible to integrate films and live programs very satisfactorily without the studio preview facilities by coordinating the operations through a private-line telephone. If

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film-projection facilities are provided at both the transmitter and the studio the remaining problem is only the film make-up and transportation for the portion of the day when film is utilized exclusively from the transmitter.

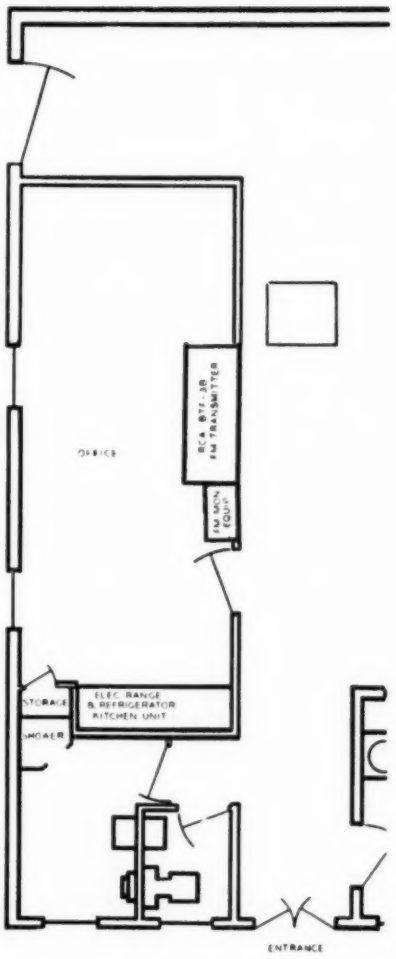
Initial Planning Considerations

In planning a television station and determining its staff requirements it is necessary to define the responsibilities of each staff member and to select and lay out the facilities so that the contemplated program schedule can be fulfilled. The small station's operating requirements are usually quite simple and can be adequately handled by combining some of the operating responsibilities to save manpower. In some instances, the purchase of additional equipment will reduce the staff requirements, and a choice may be made between spending a salary in a short period of time or amortizing an equivalent investment in equipment over a much longer period.

Inefficient initial planning will lead to difficulty in the later modification of existing operating practices because of possible opposition on the part of labor unions or fear on the part of the employees that the standard of operation may suffer. A new organization entering the television field is not bound by convention or contract with respect to the duties of its employees and it is therefore free to establish its business as it chooses. The employees will be as anxious as the management to create a new business which will profit and with which they will be proud to be associated, but they will look with alarm upon any attempt to reduce personnel requirements through the modification of an existing plant.

Analysis of Operating Functions

The requirements for the various technical operating functions in a television station are easily analyzed. The audio levels of sound on film programs have been previously monitored and the same is true of programs originating by a network or at a remote or studio broadcast. Therefore, except for program switching and initial level adjustment an audio man at a transmitter has little to do unless he is playing a record, making a recording, or monitoring a studio program. His attention may be intense for a few seconds or minutes each hour but the remainder of his time can be utilized for other duties.



The transmitter man has little to do

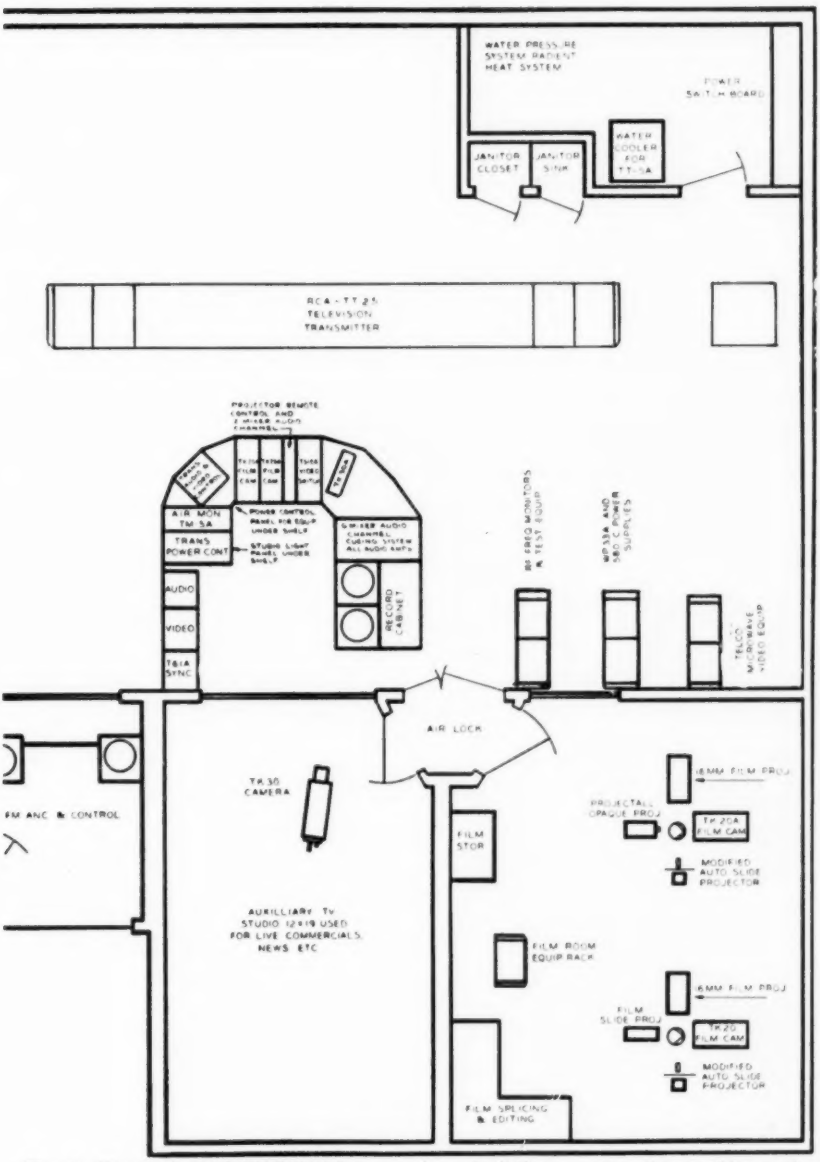


Fig. 1. Floor plan of KRON-TV transmitter building on San Bruno Mountain, showing the arrangement of its facilities. The audio and video control equipment is arranged in a U-shaped console in the transmitter room. The film equipment in the adjacent room is remotely controlled and is usually unattended. The auxiliary live studio is used for late-at-night programs. The main studios and offices are located in downtown San Francisco.

other than to check filament voltages, read the essential meters, be cognizant of the operating condition of the transmitter and to keep the FCC engineering log. The duties of audio switching and monitoring as well as the responsibility for the transmitter can be assigned to one man provided the audio equipment is located in the transmitter control room.

The addition of a video program source such as test pattern or microwave to the same man's responsibilities is no hardship provided the switching equipment for video and audio are conveniently arranged.

If film or live-camera programs are to originate at the transmitter it will be necessary to provide another man because the combination audio and transmitter man will not be able to devote enough time to shading and video levels unless the video programs are short. However, film programs of approximately ten minutes in a one-hour period may be handled by one combination audio-video-transmitter man provided the switching sequences are simple, and the film-camera control unit is conveniently located adjacent to the audio equipment in the transmitter room.

If the projection equipment is noisy, it should be located in an adjoining acoustically treated room and should be operatable by remote control. If quiet equipment is available, it may be located in the control room near the console. By careful program planning and by providing remotely controlled motion-picture and automatic slide-projection equipment as well as specially designed 95-min film reels, the manpower requirements for the film room can be reduced to only the loading of the projectors between shows. This can be easily accomplished by either the audio man or the video man during the course of a program.

Emergencies such as lamp failure in the projectors, loss of film loops, tearing of splices, etc., are relatively infrequent and can be controlled by replacing the lamps before they have been used for their expected life and by careful inspection of the film for torn sprocket holes, poor splices, etc. It is desirable to assign a person to film-room duty if the film operating load is heavy, and if opaque projection equipment requires frequent changing of slide material. It is also desirable for the person assigned to film-room duty to be responsible for the make-up of the film programs but if the film room is not easily accessible to public transportation or air express delivery service this work may have to be done at a downtown studio. In actual operating practice it is usually possible to utilize a maintenance man for film-room duty during periods of peak activity.

Description of KRON-TV

KRON-TV in San Francisco is an example of a station which was planned for maximum utilization of manpower without sacrificing operating standards. The floor plan and facilities arrangement of the transmitter building are shown by Fig. 1.

Prior to construction, the functions of the personnel were carefully analyzed and the equipment was laid out in a full-scale mock-up for operational analysis. After construction of the station, several small modifications of the plan have been made to suit operating convenience, but several years' successful operation has shown the plan to be sound, and the personnel are contented and have developed additional labor-saving innovations.

All equipment having controls is located in the U-shaped operating area designed for two-man operation when programs originate at the transmitter as shown in Fig. 2. During test pattern, downtown studio programs or network, only one man was initially required and he was responsible for the television transmitter, the film cameras, microwave facilities and audio equipment. Later additional operating requirements and other considerations resulted in the scheduling of two men during all broad-

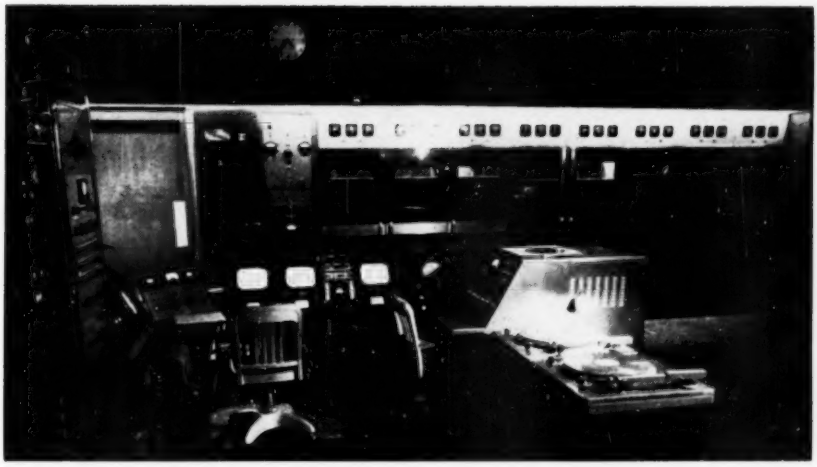


Fig. 2. The KRON-TV control area, seen from the auxiliary studio.

cast periods. The second man is responsible for video control and the loading of the projection equipment. When a live camera in the transmitter studio is utilized, a third technician is assigned to operate it. The transmitter studio is only 12 × 19 ft in area, but it is very adequate for live demonstrations using simple props and title cards. This studio is used principally for live commercials late at night, on holidays and week ends when the two large downtown studio facilities may not be available. Only one five-man studio crew was initially required to cover the entire week's live programs from the downtown studio.

Live programs are broadcast nightly from the transmitter studio utilizing one camera. This camera is usually kept in motion to add interest to the live program. It is regularly used in conjunction with 3-min film shorts featuring orchestras and talent, interspersed with a live master or mistress of ceremonies.

A staff announcer-producer is assigned at the transmitter during evening operating periods or when the downtown studio is not in operation. He is responsible for the program log, station identification and coordination of programs. Additional talent is customarily used for commercial demonstrations.

The left end of the U-shaped operating area includes the rack mounted equipment minus the power supplies. The studio-type synchronizing generator is contained in one rack; the video equipment including two microwave receivers, two stabilizing amplifiers, a video jack panel and two distribution amplifiers comprise an adjoining rack; and the audio equipment including the limiting amplifier, pre-emphasis network, magnetic tape recorder, audio jack panel, audio equalizer, and video bar generator is located in a third rack. The transmitter power console is next, and the space below the operating shelf is utilized for a studio lighting switch panel so that the technicians have control of the preset lights. Next is the "on the air" picture and waveform monitor, and then the transmitter audio-video control panel. Under the operating shelf of this console are located the power switches for the video and audio equipment. An intercommunication panel for talking to the film room, the studio, the office, shop and front door is located between the

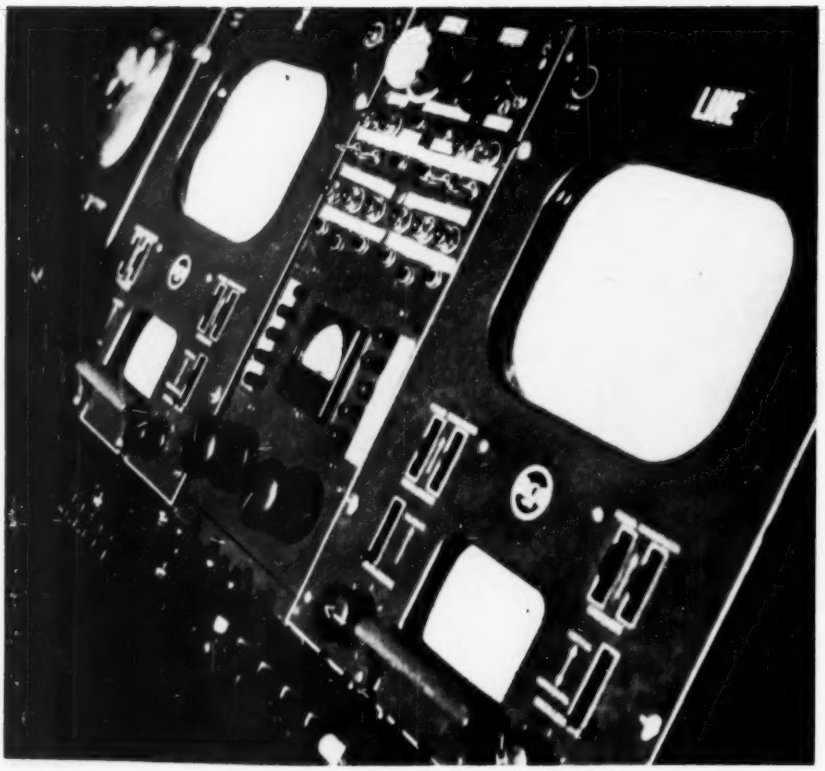


Fig. 3. Close-up of the projector remote control and two-channel audio mixer panel, located between the line monitor and film camera No. 2. The two large knobs at the top control variacs for the fixed slide-projector lamps; the upper bank of switches and tally lights are for controlling the automatic slide projectors; and the lower bank of switches and tally lights are for controlling the 16mm motion-picture projectors.

The lower part of the panel has two audio mixers, each with a choice of five inputs selected by pushbutton, and a VU meter. Below the audio mixer is a panel providing remote Start and Stop buttons for the two turntables and a magnetic tape recorder.

transmitter audio-video control panel and the control consoles for the two film cameras. Adjacent to the second film-camera control is a special console (Fig. 3), containing two variacs for the slide projectors, controls for the two automatic and fixed-slide projectors and the opaque projector, remote controls for the two 16mm film projectors, and a two-mixer audio channel providing a choice of ten audio inputs. This audio console permits one-man operation of video and audio switching since it places faders, selector switches, and remote controls for starting and stopping the turntables and magnetic tape recorders within easy reach of the operator. Since two men are usually available, the one-man operation is infrequently used. The video switcher and program monitor is next in line followed by a field-type camera control unit for the studio

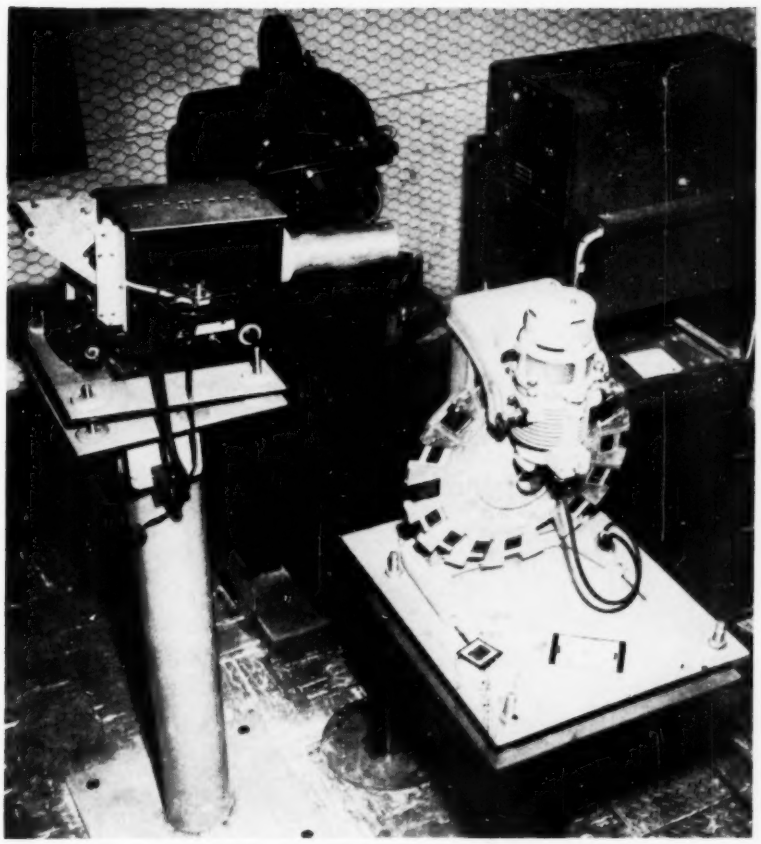


Fig. 4. One of the KRON-TV film cameras is used in conjunction with a 16mm film projector, a remotely controlled turret-type 2 × 2 slide projector, and a "Projectall" opaque or baloptican projector. The opaque projector is utilized to project a $\frac{5}{16}$-in. news tape over the bottom side of a test pattern. The bottom of the test pattern is masked out with opaque tape and is projected as a transparency through the automatic slide projector. The news tape is projected as an opaque against a black background and is optically superimposed on the test pattern. The light intensities of the projectors can be controlled by variacs so that optimum reproduction will result.

camera. Relay switching of the audio and video simultaneously has also been installed in the RCA TS10A switcher.

Completing the "U" on the righthand side is a six-channel audio console containing the equivalent of a relay rack full of audio equipment, all of the plug-in variety, and two turntables with special cuing systems and modifications for remote relay control.

The audio system provides two separate program channels, one for the two-channel mixer and the other for the six-channel mixer, and the outputs of the two channels can be combined to feed the transmitter. This flexibility is also

Fig. 5. The 95-min 16mm film reels are shown on the RCA modified TP16B projectors, with Bill Sadler, left, formerly KRON-TV supervisor, and Donald Anderson, KRON-TV engineer. This second camera is used with a 2 × 2 slide projector and an automatic slide projector.

utilized in playing recordings through one channel feeding a speaker in the studio, so that an artist may sing to the accompaniment of a recorded orchestra without danger of acoustic feedback since his voice is amplified by a separate channel.

The film-room equipment at KRON-TV is remotely controlled and is nearly automatic in operation. The automatic slide projectors (Fig. 4) have been modified for remote control from the operating console, and special cams and reversible motors have been installed. Thus it is unnecessary for a man to be in the film room to change slides and since each automatic projector is associated with one film camera, the video operator can easily preview and shade each slide before switching it on the air. The film-room equipment is laid out for maximum efficiency and continuity of operation. Since duplicate equipment is provided, protection in case of equipment failure is assured.

The original RCA TP16B 16mm film projectors have been modified by extending the reel arms and by providing specially designed Goldberg 95-min film reels as shown in Fig. 5. The new Eastman projectors are designed to be used with 4000-ft reels. Thus a one-hour kinescope recording or film feature may be spliced to film station identifications, film spot announcements and another half-hour show and run continuously on one projector. The film editing and make-up are done by the program department downtown, and the film is delivered to the technicians at the

Film Camera		Time	Program	Visual Source	Aural Source
	1	9:29:30	Sponsored Announcement (20)	F	SOF
6					
	1		Station Identification (10)	XA-2	BM
				Studio B	
	1	9:30–9:50:30	*Frisco Frankie*	Open 1 Cam	SM ET672
				F	SOF
6	2	Approx. 9:43	Film Commercial (60)	F	SOF
				Close 1 Cam	SM
6					
	1		Sponsored Announcement (20)	F	SOF
	1		Sponsored Station Identification (10)	F	SOF
				Studio B	
	1	10:00–10:29:30	*Files of Snoopy Smith*	F	SOF
6		Approx. 10:16	Live Commercial (60)	Live 2 Cam	Boom
	2		Public Service Announcement (20)	XB37	BM
	1		Sign Off (10)	XA-2	BM

Fig. 6. Example of Operating Work Schedule.

Explanation of Fig. 6

Line at left shows film-splicing order as assigned by the video-control supervisor; during this time segment all film is on one reel with black leader spliced in as indicated by wavy line (number of seconds of black leader indicated by adjacent number). Black leader provides time to stop and start projector for station identification, commercial or another program. The Sponsored Announcement (20-sec duration) at 9:29:30 is a film (F) and the audio is sound on film (SOF). The Station Identification is from a slide (XA-2) with an aural announcement from the announce booth microphone (BM). It is projected while a 6-sec black leader, spliced between the sponsored announcement and the feature film, is run through the film projector and is stopped. The opening live commercial is done on one camera (1 Cam) with a studio microphone (SM) and an electrical transcription ET672 for a theme. The film feature is started on a cue from the Program Director and runs until 9:43 when a 6-sec black leader provides time to stop and start the projector for a one-minute film commercial in film camera 2 having sound on film (SOF). The close of the program is also live and another 6-sec stop down black leader provides time to stop and start the projector.

Following the closing live commercial, the projector is again started on cue to present a 20-sec sponsored announcement, a 10-sec sponsored station identification both with sound on film (SOF) and the next feature film. At approximately 10:16 a 6-sec black leader provides time for stopping and starting the projector for a live one-minute commercial requiring 2 cameras and a microphone boom. Following the commercial, the film feature is resumed on cue from the Program Director, and at its conclusion, a slide XB37 in camera 2 and a sign off slide XA-2 in camera 1 with audio from the Booth Microphone is utilized.

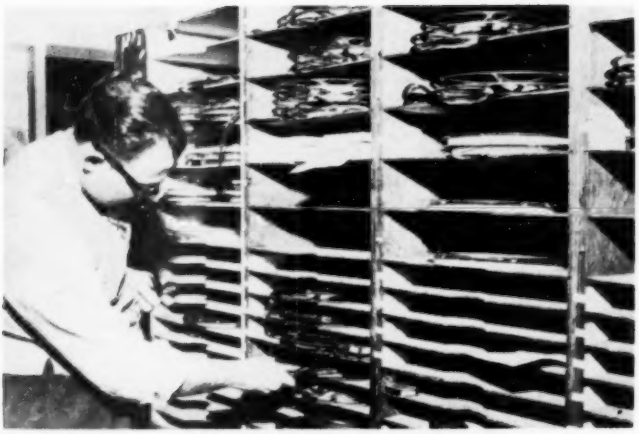


Fig. 7. After films are checked in by the station, the reels are placed in bins to await preview screening. The bins are arranged in vertical rows by the day of the week, with shelves marked for the hour the film is to be shown.

Fig. 8. Facilities for editing and splicing 16mm films. Each splicing table is equipped with one motor-driven rewind and one hand-cranked rewind. The film is spliced in accordance with instructions from the video-control supervisor as noted on the left margin of the daily work schedule shown in Fig. 6. Reel sizes are selected for the particular operating requirement.

transmitter by a messenger service. Facilities for the film make-up are included in the transmitter film room, and all technicians are familiar with the techniques.

Film Program Coordination and Responsibility

In order to achieve a semiautomatic film-room operation, it was necessary to devise a simple and complete operating work schedule. A simplified version of the schedule is shown in Fig. 6.

This work schedule was designed by KRON-TV technical operating and program personnel and includes all the necessary information regarding any equipment or facility requirements for a given program. The schedule is prepared several days in advance of the broadcast day by the Traffic Department from information supplied by the Sales and Program Departments. It is submitted to the transmitter video-control supervisor who checks the schedule with respect to film and slide equipment and personnel requirements and for any situations which are apt to cause operating difficulty. Such situations might be the scheduling of the use of a 35mm filmstrip or opaque projection material at times when only two technicians are assigned at the transmitter. Such a situation may require the scheduling of another technician to cover the film room since the film-strip and opaque projectors are manually operated. Their use is infrequent, hence there has been no need for adding automatic features to them.

While checking the work schedule, the video-control supervisor marks it to assign the slides to the remotely controlled slide projectors and to indicate the desired splicing order for the various films. It is common practice to have a 10-sec film station identification spliced to a 20-sec commercial spot which is in turn spliced to a feature film or kine recording. With the large reels, over an hour and a half of film including spots, station identifications, etc., can be spliced together. This work is normally done by full-time film editors at the downtown studios (Figs. 7 and 8). The responsibility for the receiving, inspection, cleaning, editing, splicing and shipping of the film is thus principally that of the program department, and the technicians treat the prepared film program material as though it were a transcription. The degree to which the large reels are used and the amount of splicing required depends upon the availability of technical personnel. If an extra man is available for film-room duty, he can be assigned and the film room can be operated on the basis of numerous short reels in succession. However, the smooth integration of 10-sec and 20-sec commercials into a 30-sec station break is greatly simplified by splicing them to the longer films.

Fig. 9. When the reels are ready, they are placed in these "cans" which are then locked and shipped to the station's transmitter by a messenger service. Transcriptions, records and mail are also inserted in these "cans."

In the event that a program change requires that a film be moved in the schedule, deleted or substituted, such a change is easily made since splicing equipment is available at the transmitter film room. In fact, it is not uncommon for numerous spots which are used during the Friday program to be removed by the technicians and spliced to the Saturday or Sunday film. Last-minute rearrangement of slides, or any other equipment requirement, has never created serious scheduling problems.

Television Film and Splicing Practices

The same spots and station identifications are used many times. Since they are customarily spliced by cementing them to another film, they frequently are supplied with opaque leader at both ends. These leaders are initially trimmed to 6 in. and a number of splices can be made before it is necessary to add additional black leader for splicing. Each splice results in the loss of one frame-width of film. Obviously if the splicing was not done on the opaque leader, the film would soon lose either visual or aural content.

Operating experience has indicated that splices should not be spaced closer than 3 in., otherwise there is danger of splice breakage. Some spots are supplied with "hen scratches" or writing on the black leader. This must be masked out. Black cellophane adhesive tape has been found to be suitable for such masking.

Blooping Sound Tracks. Sometimes it is necessary to "bloop" a sound track to overcome an objectionable noise when a splice passes through the sound head. A triangle of black cellophane tape applied over the sound track has been found very effective. Commercial bloop inks require more time because they must dry and they are most effective if applied with a spray gun and a mask. In practice a good audio man can minimize "bloops" with his fader after a few days' experience. He must, of course, know when they will occur in order to anticipate them.

Stop-Down Leader. In many instances it is necessary to insert an appropriate length of opaque leader in the film makeup to provide for the showing of another film or slide while the film projector continues to run without interruption. When it is necessary to stop a projector to show another film on another projector or to utilize another source of program material, approximately 4 ft of opaque leader is spliced in the film makeup to allow for stopping and starting the projector. Such a leader would be "cue" marked in the middle by the punched hole method.

Cue Marks. Adequate cue markers for 16mm film have not been generally available. The customary hole punches are large and are objectionable to the viewer. A small cue marker which punches four frames in the upper right-hand corner, outside of the television receiver mask area, has been made on a custom basis and an aural cue marker utilizing prerecorded adhesive magnetic tape will soon be available. The aural cue marker will create a signal which only the station personnel can hear and will therefore overcome the objectionable features of the visual cue.

Film Splicing Technique. Good cemented film splices are easily made and require only simple techniques which must be thoroughly understood and appreciated. The Griswold R-3 Splicer is very adequate and is used by many television stations. It is essential that the emulsion on the film be carefully scraped clean. This is easily done by clamping the film in the splicer and shearing it, then the end of the film is moistened and scraped with a well-honed scraper. The scraper must be kept sharp and clean or it will not do a good job. Care should be used not to scrape away the film base or the splice will be weak. The splicer should be well illuminated to facilitate inspection of the splice.

The film cement should be fresh and

should be kept in small bottles which should be tightly capped when not in use. Film cement is composed of very volatile chemicals which are essential for dissolving the film base. Eastman Film Cement has been very satisfactory. Most stations purchase cement in large bottles from which they refill the one-ounce bottles used at the editing table.

After a thin coat of cement is applied, the splice is clamped in the splicer for 10 sec. Then one side of the splicer is opened to admit air for another 10 sec of drying. The splice is then wiped clean of excess cement.

Film Cleaning. Much of the film supplied to television stations has been handled several times and has accumulated dirt, lint and hair. Film cleaning can be easily accomplished in commercial film cleaners utilizing a solution that cleans the film and also deposits a thin layer of wax on it for protection, or small quantities of film can easily be cleaned with soft powder puffs or velvet pads saturated in carbon tetrachloride containing a small amount of beeswax. It is necessary to ventilate film-cleaning areas since the fumes of the cleaning solvent are toxic.

Maintenance of Projection Facilities. All film-projection equipment should have regular maintenance to insure that it is clean and well lubricated. Most stations find it desirable to have one man assigned to maintain projection equipment as well as have the services of a manufacturer's service organization. It is essential to have compressed air available near the projectors to blow lint or hair out of the film gate during operation and for use during maintenance.

Film Department Staff. In addition to the technicians who operate the station, KRON-TV presently has a film-room staff of three splicers, one editor and a shipping and receiving clerk who also has other duties. The editor times film features and edits them to fit into given broadcast periods with their respective commercials. A messenger service is utilized to transport the film to the transmitter film room, which is on San Bruno Mountain approximately ten miles from the studio by road.

Conclusion

Through coordination in scheduling programs and assigning appropriate facilities, it is possible to operate a television station with essentially unattended film-projection equipment. However, consideration must be given to possible film-room emergencies which can be covered by a man who is normally assigned to maintenance.

The number of technical operating personnel of a television station can be kept small by combining some of their operating functions. Film-projection facilities installed at a transmitter plant will reduce the number of studio personnel required. However, each station's situation should be analyzed with respect to other convenience and cost factors such as program coordination, distance and condition of roads.

The methods of operation, as described in this paper, were developed by the management and staff of KRON-TV while the writer was its chief engineer. Credit is especially due to H. P. See, Manager of KRON-TV, for the inauguration of these policies, and to J. L. Berryhill, KRON-TV's chief engineer, for his assistance in preparing this paper.

Discussion

Harry R. Lubcke (Consulting Engineer): Would you say, on the basis of KRON's experience, that, if the studio were supplied with one of the remote-controlled cameras, the men would have time to manipulate that also?

Mr. Isberg: Oh, yes. These practices which I've described for KRON-TV mountain operations certainly apply to studios. In other words, I have described a divided studio and transmitter operation having film facilities and a one-camera studio at the transmitter. This camera is electrically adjusted from the operating

console in the transmitter room. Possibly I still don't understand your question.

Mr. Lubcke: No, I don't believe you do. There is a certain organization, with which I have no connection, which manufactures a camera that can be panned and tilted remotely by automatic control and I was wondering if these men of yours would have time enough to use that in a practical way?

Mr. Isberg: Since I've had no experience with it, I'm not sure. A cameraman is normally assigned to the transmitter studio, but if someone, possibly the program man, were operating the remote controls of a remotely controlled camera that was dollying itself around the floor and panning, and so forth, it might be all right.

Mr. Lubcke: May I put the question this way. The technicians have a little spare time. Could they use this equipment if they had it?

Mr. Isberg: There isn't very much time for additional technical duties as we presently operate. But by slight modifications of program formats and procedures they could probably learn to use the remotely controlled camera.

A Mathematical and Experimental Foundation for Stereoscopic Photography

By ARMIN J. HILL

The system of stereoscopic photography developed by the Motion Picture Research Council, and now generally used in the major Hollywood studios, has been based upon extensive experimental data regarding the processes involved in binocular vision. It is now known that this vision does not give absolute location of points in space, but rather that it is sensitive to small differences in distance and direction. Therefore, it appears logical to use differential rather than integral forms in calculating probable appearances of projected pictures. It is found that this approach removes many of the troublesome restrictions found in suggestions based upon other assumptions. Perspective and apparent depth can be balanced for pictures seen from the better viewing positions in motion-picture theaters. It is also possible to include necessary psychological factors to allow satisfactory photography of close-ups and other special effects. The result is that if certain simple limitations and precautions are observed, it is not difficult to obtain stereoscopic motion pictures which are consistently natural in appearance and easy to view.

THE Motion Picture Research Council has developed a system of recommendations for the photography of stereoscopic motion pictures which in many respects is quite different from most of those which have previously been suggested. Therefore it is desirable to review the basic theory of the transmission and viewing of stereoscopic pictorial information in the light of what is now known about the processes of binocular vision in order to show that the Research Council system has been established on a sound theoretical basis and that it has been possible to determine the necessary constants experimentally in such a manner that they can be considered reliable.

These recommendations have now been used in critical comparative tests in many of the studios and have found enough application in actual production to show that they are capable of giving excellent results. In fact these results have adequately demonstrated that the approach which has been used is correct, and that the mathematical foundation on

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SYMBOLS

Note: In general primed symbols refer to quantities in the projected image space (in the theater) corresponding to the unprimed quantities in the object space (before the camera). The subscript o is used when quantities are referred to the apparent position of the observer when this does not coincide with the camera position.

a Distance from plane of convergence to object
b Interaxial spacing of camera lens
e Interocular distance of observer
f Focal length of camera or lens-film distance
f_p Focal length of projector lens
G "Giantizing" factor in general equation
m Magnification as given by w'/w
m "Reduced" magnification as given by $m(b/e)$
M_s Screen magnification as given by W_s/w_p
p Distance from camera to plane of convergence
s Integrated angular distance in perceptive space
u Width of object not in plane of convergence
v Distance from observer to theater screen
w Any horizontal distance in the plane of convergence
w_p Width of projector aperture
W_s Width of projected picture on screen
θ Angle of elevation in bipolar coordinates
ϕ Bipolar latitude
γ Bipolar parallax or angle of convergence
η Distance factor
ρ Distance (or nearness) ratio
σ, μ Luneburg Constants
τ Modified bipolar parallax given by $\sigma(\gamma + \mu)$

which it rests will probably serve as well in solving future problems in this type of photography as it already has in solving some of the more basic ones.

The Research Council System

The system of recommendations developed by the Research Council is characterized by several features which are either different, or which are treated differently from those in other systems. The more important of these are:

(a) *Use of a relatively, but not absolutely, fixed interaxial spacing:* The interaxial spacing is found to be related to the focal length of the lenses rather than to depend only upon the distance from camera to object. Therefore it is varied in a manner quite different from other stereographic systems.

(b) *Allowance of limited divergence in lines of sight:* Lines of sight to background points can be allowed to diverge slightly. The amount of this divergence is strictly limited in accordance with reliable data from numerous optometric tests, and a factor of safety is allowed so that no one with normal vision will have any difficulty viewing such points. However this slight divergence allows a freedom of camera setting and motion not possible with most of the other systems.

(c) *Establishment of forescreen reference planes:* Two reference planes are established for control of forescreen action. One of these is the limit for maintaining good proportion in the appearance of the projected picture. The other limits the distance objects can be forescreen and still be seen distinctly.

(d) *Special treatment of close-ups:* The psychological effect of the close-up has been taken into account to make possible very acceptable close-up photography.

(e) *Special formulation for distant shots:* The general formula which has been developed shows that distant shots require a somewhat special treatment. This has been applied with very satisfactory results.

(f) *Use of "normal" procedures on the set:* Perhaps one of the most distinctive and desirable features of this system is that it requires few changes in accepted camera

techniques. The cameramen and assistants handle all the necessary calculations. Distances are measured from the camera in feet and inches. Camera motion is used in about the same way as it has been for "flat" photography. Long, medium and close shots are used in about the same proportion, and the use of different lens focal lengths can be very similar to that which has previously been accepted as good practice. In short, most of the techniques which are already well known to experienced cameramen can be used with good effect in this new medium.

In addition to these special features, this system has several which are common to most of the other systems of stereoscopic photography. Among these may be mentioned:

(a) The establishment of a "plane of convergence" in the set which will correspond to the plane of the screen in the theater.

(b) The establishment of geometric image positions according to generally accepted principles of stereoscopic transmission.

(c) The use of sheet polarizers in projector filters and viewers, use of dual cameras and double film in taking the pictures and (at present) of double synchronized projection, with individual viewers required for each spectator, all of which are common to most of the systems being used successfully in the presentation of stereoscopic pictures to theater audiences.

How Does This System Differ From Others?

Most of the systems which have been proposed for the photography of stereoscopic motion pictures are based on the assumption that binocular vision gives an absolute estimate of distance and a definite indication of the angles taken by the lines of sight in viewing an object. It is therefore necessary to have the projected image points so related to each other that lines of sight for a spectator in the theater will have the same direction as the corresponding lines for the taking camera.

An immediate consequence of this assumption is that the interaxial spacing must be proportional to the distance from the camera to the object, and in most of the suggested formulae the required spacing is so small for practical taking distances and reasonable screen sizes that the results invariably show the distortion referred to as "cardboarding" wherein the objects appear to be flattened into distinct planes at varying distances from the camera.

Another assumption which has been made quite generally and which has some experimental justification is that under no conditions should lines of sight to corresponding image points ever be allowed to diverge. It can easily be shown that this assumption makes impossible the photography of "deep" scenes and their subsequent projection upon full-sized theater screens unless the interaxial spacing is again reduced to such an extent that "cardboarding" is apparent.

Modern research in the process of binocular vision has adequately shown that such vision does not, of itself, give much information on the absolute distance of an object from the eyes. Neither is there any mechanism in the visual processes which indicates the angles of the lines of sight. On the other hand, binocular vision gives a very sensitive indication of relatively small *differences* in distances and of small *differences* in the directions of the lines of sight. It is these differences which are used to give the binocular depth effects upon which successful stereoscopic photography depends. Therefore any theory which is to give successful results must logically be based upon these differences of distance and direction rather than upon total or absolute values.

When such a theory is used, it becomes apparent that the binding limitations of the other assumptions are no longer

valid. The interaxial spacing need not be proportional to the taking distance, and since the eyes cannot detect the actual directions of the lines of sight, there is no real reason that these lines cannot diverge slightly. It is therefore possible to photograph pictures in such a manner that all dimensions of an object will *appear* in natural proportion, and these proportions can be balanced with the perspective so that within acceptable approximations, at least, the projected stereoscopic pictures will appear as the natural scene did from the apparent camera position.

The projected picture will no longer have the same geometric proportions as the natural scene, but will *appear* to have them when viewed from the better positions in an average theater. Distortions which are caused by viewing the picture from an angle, as from a side seat, or which vary with the viewing distance, of course cannot be eliminated. However, it can be shown that over a comparatively large viewing area stereoscopic pictures can appear to have very acceptable proportions. This is quite definitely in contrast to the concept of the "orthostereoscopic" position based upon the strictly geometric assumptions of other systems.

In order to obtain the proper effects, clues which may reveal the absolute distance to projected image points must be suppressed, and it may not always be possible to do this. Then it becomes necessary to take the conflicting effects into account and work out an acceptable compromise.

Experience has shown that in most actual situations the theory which is presented here gives effective and satisfying results. Necessary modifications can be made without guesswork or extensive testing. Most important of all, the results appear natural and are easy on the eyes, giving a very pleasing overall effect.

I. THE BASIC FORMULAE FOR STEREO-TRANSMISSION

The Three Spaces

It is convenient in discussing the principles of stereo-transmission to speak of the *object space* as that in front of the camera, the *projected image space* as that containing the geometric image positions in the theater, and the *perceptive*, or *apparent image space* as that containing the image points as they appear to be related to each other in the perception of the spectator. In this portion of the discussion we shall be interested in the relationship between the object space and the projected image space. Later we will show how the transformation can be made into the perceptive image space so that we can predict approximately the results as they will appear to the observer.

The Plane of Convergence

First, let us determine those reference points which are common to both the object and projected image spaces. If two projectors are properly aligned and used to project identical prints on the screen simultaneously, these prints should exactly overlap — at least at the center. Accepted practice now uses this same alignment for projecting stereoscopic pictures. Since these prints are each guided from one edge, this means that corresponding point pairs which are exactly the same distance from these edges will exactly coincide on the screen, and will therefore appear to be in the plane of the screen.

A little consideration will show that such point pairs will represent object points which are in an approximately plane surface at some distance in front of the camera, and perpendicular to the direction in which the camera is pointed. This assumes of course that the lenses are properly matched and that other factors

are such that the two pictures are very nearly the same size.

Let us refer to this (approximate) plane in the object space which contains those points whose stereoscopic image point pairs coincide at the plane of the screen in the image space, as the *plane of convergence.*

Principal and Photographic Axes

Now let us define the principal stereoscopic axes of the two lens-film systems in the stereoscopic camera as those optical rays drawn through the lens nodal points from the points on each film which will be projected at the center of the screen. These will not necessarily coincide with the optical axes of the systems. However if they are extended far enough into the object space, they will intersect in the plane of convergence. The angle between these two axes is known as the convergence angle, or sometimes as the convergence parallax.

Of more practical use to the cameraman are the *photographic axes*, which are defined as those through the centers of the equivalent projector apertures in the camera film plane and the nodal points of the respective lenses. These axes will coincide with the principal axes only when the position of the film relative to the camera lens, the handling of the film through processing, and the alignment of the projectors are all such that the projector aperture as outlined in the camera ground glass coincides with the area of the film which is actually projected on the screen.

The Plane of Convergence and the Screen Plane

In order that the photographic and principal axes will be coincident, and therefore that the intended plane of convergence will actually coincide with the screen plane, it is customary to align the cameras so that their photographic axes coincide on some well-defined vertical object which is in the intended plane of convergence. If the stereoscopic images of this object then coincide when projected on the screen, it is known that the axes are properly aligned and that alignment has been maintained through the film processing and projection.

With the definitions we have given, it is apparent that the plane of convergence in the set (object space) becomes the plane of the screen in the theater (image space). Furthermore, unless correction is to be made in processing or projection, this plane will be that containing the points upon which the photographic axes of the camera actually converge. Therefore it is convenient to use it as the basis for the mathematical relationships between the object and projected image spaces.

A plan view of the geometry involved in this relationship is shown in Fig. 1. Here three points are represented along a line from the camera perpendicular to the plane of convergence. Point A is at the plane of convergence in Fig. 1 (a), and so its two image points coincide at the screen in (b). Point B is nearer the camera and its image points are therefore doubled so that the one seen by the right eye (B'_R) is to the left of the one seen by the left eye (B'_L). The lines of sight from the observer at point O will therefore intersect at (B') which is the *geometric image point* of the object point B. The point C is beyond the plane of convergence. Therefore, (C'_R) is to the *right* of (C'_L), and the lines of sight intersect behind the screen plane at the image point C'.

Let us use p for the distance from the camera to the plane of convergence and a (with suitable subscript) for the distance from this plane to an object point. In the image space, let v represent the distance from observer to screen, and a' the distance from the screen to the image point. (In each case distance away from the camera or observer is considered positive, that toward them negative.) The interaxial spacing of the camera lenses (distance between front nodal points) is indicated by b. The

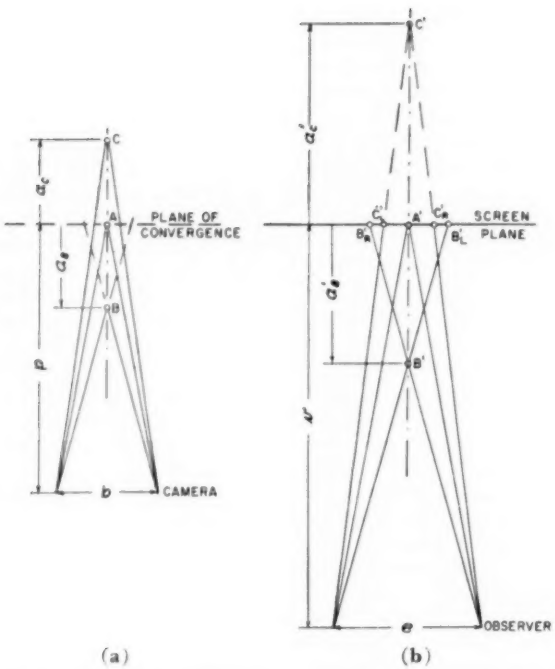

Fig. 1. Lines of sight in taking and viewing stereoscopic pictures.

interocular of the observer is e. Any width (or other dimension in the plane of convergence) will be designated by w with an appropriate subscript when in the object space and by a corresponding w' in the image space. Focal length of the camera lenses will be designated by f, and this will also be used to designate lens-film distance, since for all but a few special cases this will be effectively the focal length. The focal length of the projector will be designated by f_p.

Magnification

The *screen magnification*, M_s, is the ratio of a linear dimension in the projected picture on the screen to the corresponding dimension on the film. It can be found by dividing the projection distance by the lens-film distance in the projector, or for practical purposes by dividing the projection distance by f_p. It may also be found by dividing the width of the projected picture on the screen (without masking), W_s, by the width of the projector aperture, w_p, which for standard projection is 0.825 in.

A more convenient quantity in the mathematical development given here is the overall *magnification* of the photographic-projection process. This will be designated by m and is defined as the ratio of a linear dimension of an image in the plane of the screen to the corresponding dimension in the plane of convergence. For example, if a man 6 ft tall is photographed in the plane of convergence, and his projected image on the screen is 18 ft tall, the magnification is 3.

Distance Ratios and Factors — Nearness Ratios

Let us now refer to Fig. 2, which is

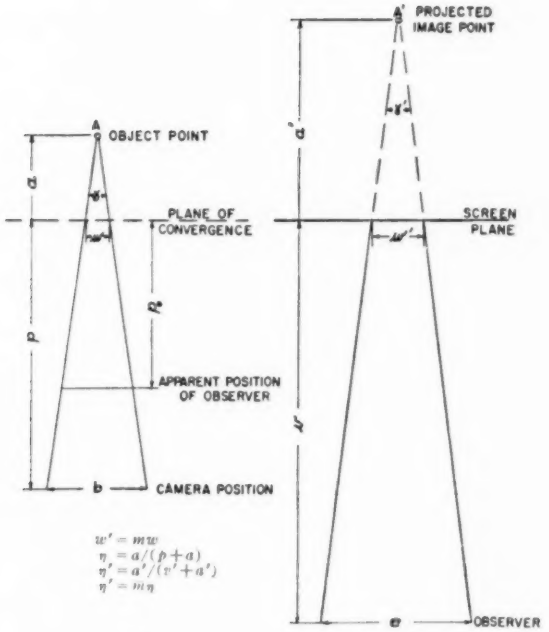

Fig. 2 Geometry of stereoscopic transmission.

similar to Fig. 1, except that it shows only a single point A which is at a distance a behind the plane of convergence. The point may just as well be in front of this plane, in which case a becomes negative, or at the plane of convergence in which case a is zero. It is seen that by using similar triangles

$$\frac{a}{p} = \frac{w}{w+b} \quad \text{and} \quad \frac{a'}{v} = \frac{w'}{w'+e} \qquad (1)$$

Let us designate the ratio a/p as the *object distance ratio*, and a'/v as the *image distance ratio*. When a' is negative, the absolute value of a'/v can also be referred to as the *nearness ratio*.

It will be noticed that the image distance ratio depends only upon the value of w' and e. Therefore it will be the same for all observers who have the same interocular, and since the interocular does not vary a great deal from one person to another, we can say in general that the image distance ratio is practically the same for all observers in the theater.

It is sometimes more convenient to use *distance factors* rather than distance ratios. These are given in the form

$$\eta = \frac{w}{b} = \frac{a}{p+a} \qquad (2a)$$

for the object space and

$$\eta' = \frac{w'}{e} = \frac{a'}{v+a'} \qquad (2b)$$

in the image space.

The Basic Formula for Stereo-Transmission

Now, from the definition of the magnification we have

$$w' = mw \qquad (3)$$

Table I. Distance Factors and Ratios in the Image Space.

Geometric image position	Distance factor	Distance ratio	Spottiswoode's[1] nearness factor
At infinity	1	Infinity	0
At screen plane	0	1	1
0.5 way from screen to observer	−1	−0.5	2
0.8 " " " "	−4	−0.8	5

so that

$$\eta' = m(b/e)\eta \qquad (4)$$

or in still simpler form

$$\eta' = \bar{m}\eta \qquad (5)$$

where $\bar{m} = m(b/e)$ is known as the *reduced magnification*, or in the Research Council system simply as the "M value." We have here, then, a very simple and convenient expression which relates all the essential information in the projected image and object spaces. In other words, it is the basic equation of stereo-transmission between these spaces.

If we use ρ and ρ' to represent the distance ratios, it is easily seen that these are related to the distance factors by the equations

$$\rho = \eta/(1 - \eta) \text{ and } \rho' = \eta'/(1 - \eta') \qquad (6)$$

and conversely

$$\eta = \rho/(1 + \rho) \text{ and } \eta' = \rho'/(1 + \rho') \qquad (7)$$

Table I gives the distance factors and ratios for various points in the image space and compares them with the "nearness factors" suggested by Spottiswoode.[1] Note that the nearness ratio which we have defined as the absolute value of the distance ratio actually specifies the relative distance of the image point from screen to the distance of the observer from screen. Also, it is seen that the numerical value of the distance factor is one less than Spottiswoode's nearness factor.

One of the most noticeable effects when stereoscopic pictures are projected on full-sized theater screens as contrasted to their projection on the comparatively small screens used in

Table II. Nearness Ratios in Object Space for Different M Values.

Nearness ratio in theater	Nearness ratios in front of camera for given $\bar{m}$								
	$m \rightarrow 1$	2	3	4	5	6	7	8	10
0.1	0.10	0.05	0.03	0.03	0.02	0.02	0.02	0.01	0.01
0.2	0.20	0.11	0.08	0.06	0.05	0.04	0.03	0.03	0.02
0.3	0.30	0.18	0.12	0.10	0.08	0.07	0.06	0.05	0.04
0.4	0.40	0.25	0.18	0.14	0.12	0.10	0.09	0.08	0.06
0.5	**0.50**	**0.33**	**0.25**	**0.20**	**0.17**	**0.14**	**0.12**	**0.10**	**0.09**
0.6	0.60	0.43	0.33	0.27	0.23	0.20	0.18	0.16	0.13
0.7	0.70	0.54	0.44	0.37	0.32	0.28	0.25	0.23	0.19
0.8	**0.80**	**0.67**	**0.57**	**0.50**	**0.44**	**0.40**	**0.36**	**0.33**	**0.29**
0.9	0.90	0.82	0.75	0.69	0.64	0.60	0.56	0.53	0.47
1.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Note: The ratios of 0.5 and 0.8 (in image space), shown in boldface, are those recommended as reference "near points" in the Research Council system. These are discussed more fully in a later section.

amateur photography is the distortion in any subject matter which comes forescreen. The reason for this is at once apparent when we consider the relationship between the nearness ratios in the image and object spaces for theater screen projection. Using Eq. (5) and the relationship of Eq. (7), we find that

$$\rho = \frac{\rho'}{m + (m - 1)\rho'} \qquad (8)$$

from which we can tabulate the nearness ratios (absolute values of distance ratios) for the object space to give a specified ratio in the theater for various reduced magnification values. In most cases this reduced magnification value will be of the order of 3 or more, and for close-ups may approach 10. The small distance which any object can be toward the camera from the plane of convergence under these conditions is quite apparent from the values given in Table II.

II. THE TRANSFORMATION TO PERCEPTIVE SPACE

So far, we have considered only the geometric configuration of the image points in the projected space and their relationships to corresponding points in the object space. While these relationships are very useful in establishing certain important limitations which will be discussed later, they tell us but little about how the picture will appear to an observer in the theater. In order to obtain this information, we must consider the processes of perception, and if possible, transform our geometric forms from projected image space into perceptive space. In doing so, we will of course expect that no mathematical results will adequately account for the wide variety of differences found between individuals, and we must also expect that many important factors will be overly simplified or perhaps neglected entirely. Such an approach, however, has been found to give a formulation for setting the camera which is quite different from any obtained by using only the geometric image space, and under actual test conditions the results have adequately demonstrated the soundness of taking the perceptive space into consideration as adequately as has been possible.

An apparently reasonable, but nonetheless mistaken, assumption often made in establishing the theory of stereoscopic photography, is that in some manner binocular vision serves as a "range finding" device and thereby gives a good estimate of the actual distance to an object. Everyday experiences show, however, that if we have no information other than that given by stereopsis, or if the information we have is not in accord with previous experience, we can be badly fooled in our estimates of distance. Carefully conducted tests have adequately confirmed such experiences and have shown that we cannot make an accurate estimate of distance on the basis of stereopsis alone.

Charnwood[2] points out that no mechanism has been found in the extraocular muscles which would give information on the actual positions of the eyes essential for "range finding." He further shows that such "proprioception" would actually be a hindrance to binocular vision. Ogle[3] states that while "the phenomenon of stereopsis provides the most vivid and accurate *relative* depth discrimination, absolute localization probably results from a more complex psychic integration of empirical and stereoscopic stimuli." Luneburg[4] shows that as a result of experiments with an isolated point "binocular observation of a single point does not differ from monocular observation. Both are equally uncertain as to correlating a sensed point P to the physical coordinates of the stimulating point P^*." Charnwood[2] concludes after analyzing extensive data from many recent studies on the subject that "stereopsis has no scale and is capable

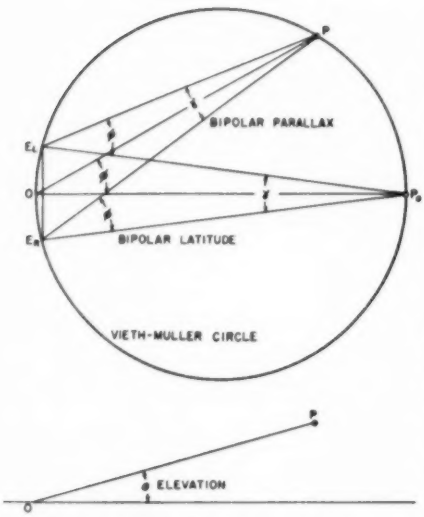

Fig. 3. Modified bipolar coordinates.

of many interpretations, the choice of interpretation being made in response to some outside factor."

Therefore there seems to be general agreement on two points: (1) stereopsis gives a very accurate *relative* depth discrimination, i.e., it will tell the observer which of two object points that are not too widely separated in space is the nearer; and (2) binocular vision cannot, of itself, give a reliable estimate of actual or absolute distance from an observer to an isolated object point. Incidentally, these are in agreement with other sensory perceptions, for in general it is found that while we can perceive *differences* in sensation, we have no direct sensation of absolute values.[5]

Mathematical Formulation — Modified Bipolar Coordinates

Mathematically, these experimental results indicate that we should use differential relationships in treating these problems of perception. Upon integration, we then have arbitrary constants corresponding to the indeterminate absolute values which seem to be inherent in the visual processes. These constants can then be evaluated upon the basis of experience or other empirical knowledge, just as we now evaluate them in constructing a perception from our sensory information.

It must be kept in mind, in treating problems of vision, that the eyes "see" only the angles between two object or image points, and all estimates of distances must be made in terms of these angles. Therefore a suitable coordinate system for relating points in the projected image space and the eyes of the observer should use angular values. The "modified bipolar coordinates" suggested by Luneburg[6] are well suited to this purpose and will be used here. Figure 3 shows these coordinates in terms of the "Vieth-Muller circle" through the observer's eyes. The *angle of elevation* (θ) gives the angle of the object point above a horizontal plane through the eyes. The *bipolar latitude* (ϕ) gives the angular displacement in the horizontal direction, or in other words the angular width. The *bipolar parallax* (γ) gives the displacement toward or away from the observer, and therefore indicates what we refer to as "depth." All three coordinates will have zero values for a point infinitely far away, on the horizontal plane through the eyes, and in the meridional plane.

The Basic Assumption

It seems reasonable to assume that the natural results in stereoscopic photography will be achieved when the dimensions, i.e. height, width and depth, of an object will appear to have the same proportion in the perception of the observer when he views the projected picture, as they would have had he viewed the object directly from the position where apparently the picture was taken. Unless the camera or projection lenses have bad distortion, the height and width will be maintained in proper proportion, so that the above assumption can be expressed in differential form in

modified bipolar coordinates by the equation

$$\frac{d\gamma'}{d\phi'} = \frac{d\gamma}{d\phi_o} \tag{9}$$

where the primed values represent those for the observer in the theater and the unprimed values those for the same observer if at some position (O) from which the picture was apparently photographed. A more convenient form is obtained by rearrangement, giving:

$$\frac{d\gamma'}{d\gamma_o} = \frac{d\phi'}{d\phi_o} \tag{10}$$

Of course, if this equation holds, it means that only a small region in the projected image space will appear to have depth in proper proportion to width (or height). However it will be shown later that this equation can be integrated, following suitable geodesics in perceptive space, and the results of such integration indicate that proper proportions will be retained within practical tolerances throughout the entire picture area when the conditions expressed by Eqs. (9) or (10) hold.

Actually, except for a single viewing distance, the position from which the picture will appear to have been taken will not coincide with the actual camera position. For a given focal length of lens, therefore, there will be a single "normal" viewing distance, but at this distance *perspective and stereoscopic depth will be properly balanced*. With other focal lengths, or at other viewing positions, the observer will appear to occupy a position (O) shown in plan view in Fig. 4. Here let u represent a horizontal dimension near the object point A (which is not in the plane of convergence). The angle it subtends at the camera is ϕ, and at the apparent position of the observer is ϕ'. The distances intercepted in the plane of convergence are w, and w_o, respectively. When projected, the distance w becomes w', and u will appear as u'. The angle subtended at the position of the observer in the theater by w' will be ϕ'. From Eq. (3) we have

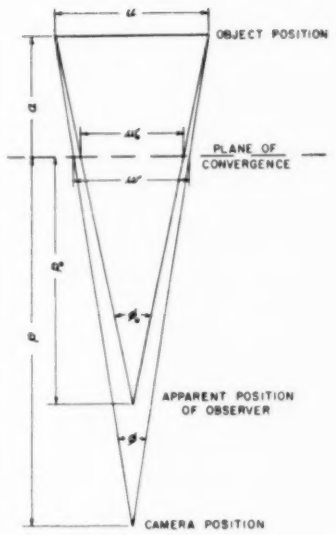

Fig. 4. Geometry for photography of an extended object.

$$u' = mw \tag{3}$$

and from similar triangles we see that

$$\frac{w_o}{u} = \frac{p_o}{p_o + a} \quad \text{and} \quad \frac{w}{u} = \frac{p}{p + a} \tag{11}$$

so that

$$\frac{w}{w_o} = \frac{p}{p_o}\,\frac{p_o + a}{p + a} \tag{12}$$

and

$$w' = mw_o\,\frac{p}{p_o}\,\frac{p_o + a}{p + a} \tag{13}$$

then, since $d\phi = dw_o/p_o$ and $d\phi' = dw'/v$, we have

$$\frac{d\phi'}{d\phi_o} = m\,\frac{p}{v}\,\frac{p_o + a}{p + a} \tag{14}$$

To obtain the relationships for the bipolar parallax angles, it is best to use the sketch given in Fig. 5. From this it can be seen that (since all angles are very small):

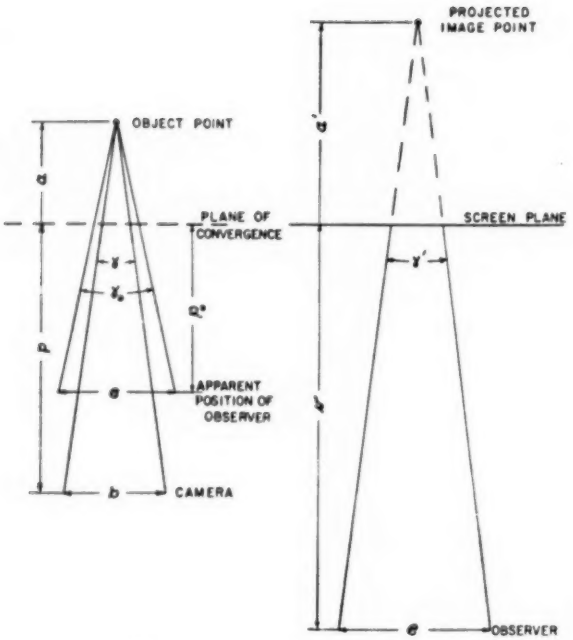

Fig. 5. Bipolar parallax in photography and viewing.

$$\gamma = \frac{b}{p + a}, \gamma_o = \frac{e}{p_o + a} \text{ and } \gamma' = \frac{e}{v + a'}, \tag{15}$$

Therefore

$$d\gamma' = -\frac{eda'}{(v + a')^2} \tag{16a}$$

$$d\gamma_o = -\frac{eda}{(p_o + a)^2} \tag{16b}$$

or

$$\frac{d\gamma'}{d\gamma_o} = \frac{(p_o + a)^2}{(v + a')^2}\frac{da'}{da} \tag{17}$$

Now from Eq. (5) we have

$$\frac{a'}{v + a'} = m\frac{b}{e}\frac{a}{p + a} \tag{18}$$

from which we obtain by differentiation

$$\frac{vda'}{(v + a')^2} = m\frac{b}{e}\frac{p\,da}{(p + a)^2} \tag{19}$$

giving

$$\frac{da'}{da} = m\frac{b}{e}\frac{p}{v}\frac{(v + a')^2}{(p + a)^2} \tag{20}$$

which, when substituted in equation (17) gives

$$\frac{d\gamma'}{d\gamma_o} = m\frac{b}{e}\frac{p}{v}\frac{(p_o + a)^2}{(p + a)^2} \tag{21}$$

Equating this to the right member of Eq. (14), we find that the condition for which Eq. (10) is valid is that

$$m\frac{p}{v}\frac{(p_o + a)}{(p + a)} = m\frac{p}{v}\frac{b}{e}\frac{(p_o + a)^2}{(p + a)^2} \tag{22}$$

or that

$$b = e\frac{(p + a)}{(p_o + a)} \tag{23}$$

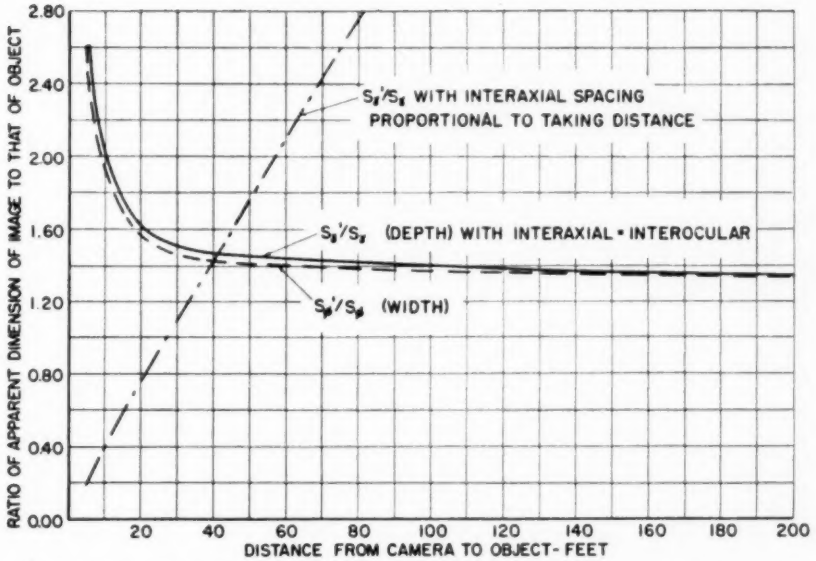

Fig. 6. Ratios of integrated apparent dimensions in projected image to corresponding apparent dimensions in object. These curves were calculated using equations (26) and (27) under the following assumed conditions: Viewing distance in theater is 40 ft. Screen width is 24 ft. Object has a depth of 3 ft and near edge is in plane of convergence at all camera distances. Focal length of camera lenses is 2 in. Interaxial spacing for solid curve is 2.5 in.

This is the fundamental equation for determining the interaxial spacing so that all dimensions will appear in natural proportion and that perspective and stereoscopic depth will be properly balanced. When conditions are such that the observer feels he is actually at the camera position — in other words, that $p = p_o$ -- this equation simplifies to

$$b = e \qquad (24)$$

The correct interaxial spacing under these conditions is therefore the interocular distance or about 2.5 in.

Integration to Include Regions of Finite Size

The above derivation of course treats only with infinitesimally small regions in the picture. There is no assurance that the same conditions will hold over finite regions unless we can obtain an integral form of Eq. (10).

Fortunately, the geometry of perceptual space under conditions similar to those used in viewing motion pictures has been formulated by Luneburg,[6] and his equations provide a simple means by which this integration can be performed. He proposes as a suitable metric for this space

$$ds^2 = \operatorname{csch}^2\sigma(\gamma + \mu)(\sigma^2 d^2\gamma + d\phi^2 + \cos^2\phi d\theta^2) \qquad (25)$$

where the angles are those which have already been defined and σ and μ are constants which vary somewhat from individual to individual.

For simplicity we can use $\tau = \sigma(\gamma + \mu)$.

Apparent distance along any coordinate line, i.e. with only one variable

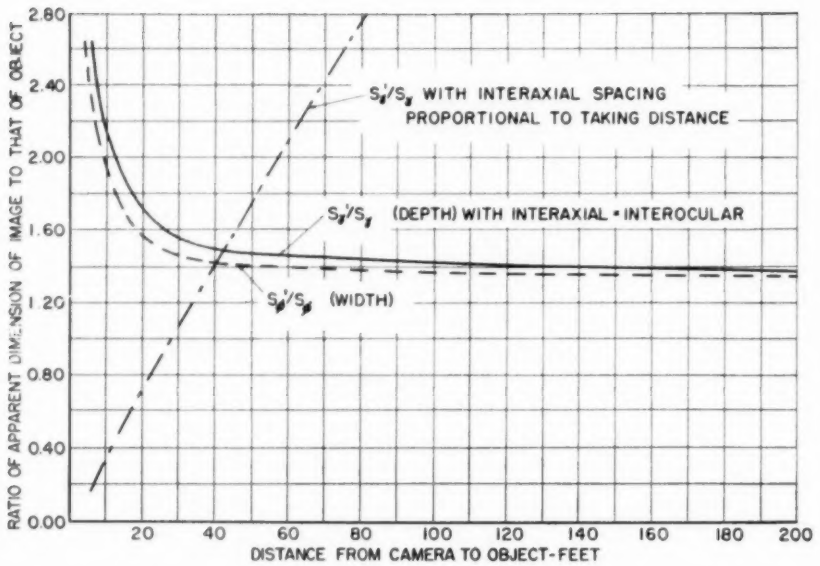

Fig. 7. Ratios of integrated apparent dimensions in projected image to corresponding apparent dimensions in object. These are calculated under the same assumed conditions as those in Fig. 6, except that the object is assumed to have a depth of 20 ft.

changing at a time, can be obtained by integrating Eq. (25), assuming the differentials of the unchanging coordinates as zero. Thus a change in apparent depth, s_γ, would be given by

$$s_\gamma = \int_{\tau_1}^{\tau_2} \operatorname{csch} \tau d\tau = \log_e \tanh (\tau_2/2) - \log_e \tanh (\tau_1/2) \quad (26)$$

Likewise an apparent width (angular) is given by

$$s_\phi = \operatorname{csch} \tau \int_{\phi_1}^{\phi_2} d\phi = (\phi_2 - \phi_1) \operatorname{csch} \tau \quad (27)$$

and apparent height (again angular) by

$$s_\theta = \operatorname{csch} \tau \cos \phi \int_{\theta_1}^{\theta_2} d\theta = (\theta_2 - \theta_1) \operatorname{csch} \tau \cos \phi \quad (28)$$

These distances are all given as angles, but as has been pointed out before, it is these very angles which the eyes use, and only through them can any estimate of actual distance be made. The condition, therefore, that apparent dimensions shall be in the same proportion as if the observer had been at the camera position will be given by the equations

$$s_\gamma'/s_\gamma = s_\phi'/s_\phi = s_\theta'/s_\theta \quad (29)$$

where the primed values represent those seen in the theater and the unprimed ones those which would have been observed at the camera position.

Actually, due to the forms of Eqs. (26) to (28), these cannot be exactly consistent. For example, Eq. (28) has a cos ϕ factor which does not appear in Eq. (27). This indicates that there will be a slight barrel distortion toward the edges of the field of view, and this may not be the same in the theater and before the camera when the other factors are selected for best balance. The error will be proportional to the *differences* in cosines of the angular field of view, however and within the range ordinarily used in

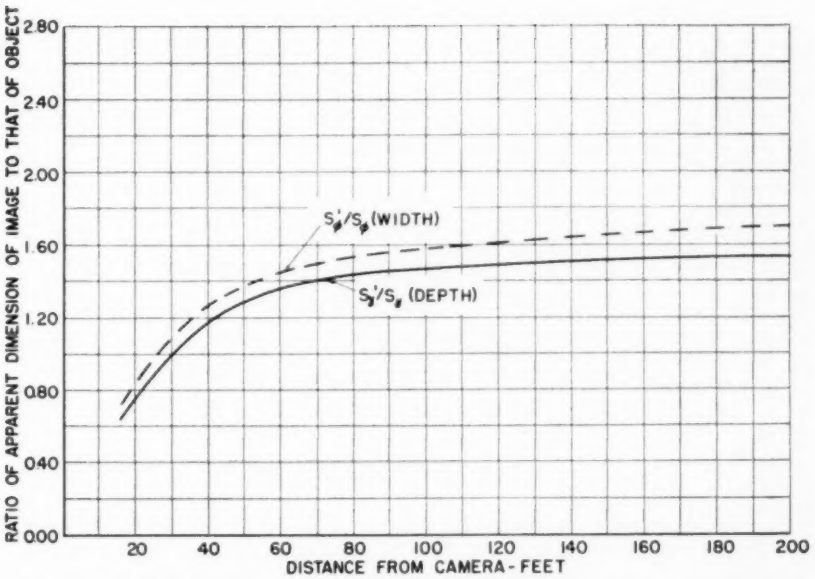

Fig. 8. Ratios of integrated apparent dimensions in projected image to corresponding apparent dimensions in object where the observer is apparently between the camera and the object. In these curves, the object depth is assumed to extend from the plane of convergence back to indicated distance from camera, and therefore varies with distance whereas in Figs. 6 and 7 it was assumed to be constant. Here the plane of convergence is assumed to be kept constant at 30 ft from the camera. Screen width is 24 ft, and viewing distance is 700 in. or 58.3 ft. Focal length of camera lenses is 3 in. and interaxial spacing is fixed at 3.5 in. This gives a picture which appears as if viewed from a point 20 ft in front of the plane of convergence.

motion-picture projection, this will probably never be serious.

If we assume therefore that the horizontal and vertical components s_ϕ, and s_θ, respectively, are proportional to each other, the condition that the depth will also be in proportion is that

$$s_\gamma'/s_\gamma = s_\phi'/s_\phi \qquad (30)$$

It is easiest to check this relationship by plotting these ratios for specific conditions, as has been done in Figs. 6 and 7. These plots show clearly that under the assumption that interaxial spacing is the same as the interocular distance, dimensional proportions will hold quite closely for all camera distances except those used for the largest close-ups. Of course these assume that lens focal lengths and viewing conditions are such that the observer feels that he is at the camera position. A more general case is shown in Fig. 8, where the apparent position of the observer is between the camera and the plane of convergence.

In order to compare the results of the above relationships with those based upon the assumption that the interaxial distance should vary with distance from camera to object, similar dimensional ratios for the latter assumption have been plotted in dashed lines in each of Figs. 6 and 7. The error in this assumption is immediately evident, for at only one distance (orthostereoscopic

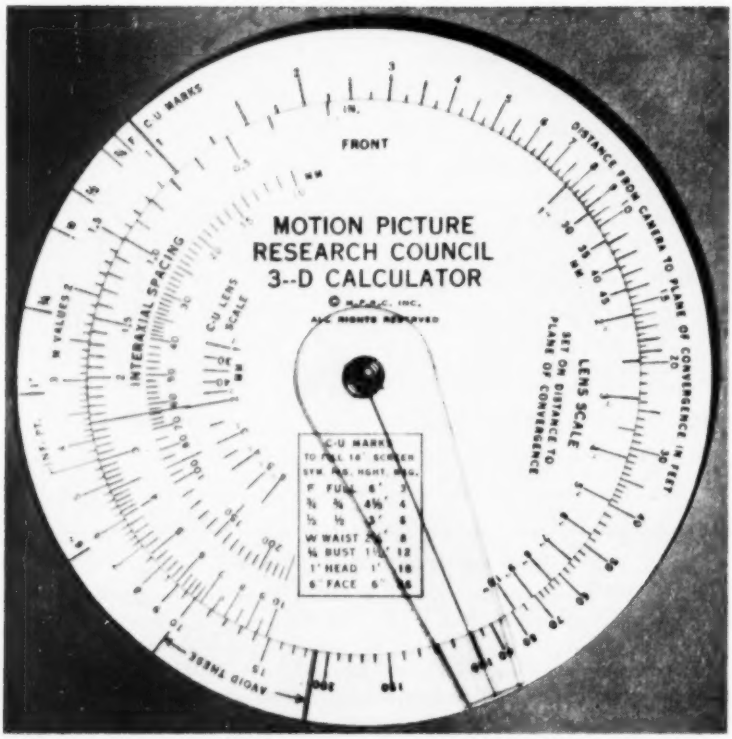

Fig. 9. The Motion Picture Research Council 3-D Calculator. This instrument, which is of white vinylite 4 in. in diameter, was designed in accordance with the principles set forth in this paper. It is now in use in the major motion-picture studios in Hollywood for the calculation of camera settings for their stereoscopic photography.

condition) are the dimensions in proper proportion.

The General Equation

A very important psychological factor has been disregarded in our discussion so far. We have long been accustomed to the use of the "close-up" in making figures on the screen appear to be very near. Most of the projected images are, of course, magnified, but these close-up views are actually "giantized." They have become so basic a part of the motion-picture convention, however, that we readily accept this giantization as normal.

When close-ups are to be photographed stereoscopically, this effect must be taken into account, and a correction made for this "giantizing." Since we unconsciously feel that we are looking at a figure much larger than normal, the correct interaxial spacing will be less than that normally used for medium shots. To allow for this, a "giantizing" factor G can be inserted in Eq. (23), giving the general equation

$$b = \frac{r\,(p + a)}{G\,(p_o + a)} \tag{31}$$

Good judgment and experience must be

used in assuming the values for G, p_o/p, and a in this equation, and the selection will depend upon the kind of shot which is to be made. The ratio p_o/p will also, of course, depend upon the viewing distance and other conditions in the theater. Fortunately it has been found possible to make acceptable working assumptions for each of these values, so that satisfactory results can be obtained consistently. These have been used by the Research Council in the construction of a calculator illustrated in Fig. 9, which gives the best recommended settings for various lens focal lengths, camera distances and other conditions.

Practical Forms of General Equation

The selection of a suitable value for a depends on the "field of interest" in front of the camera. This is usually a more restricted area than the field of view, and its depth can often be given as a proportional part of the camera distance. For example, let us assume that the field of interest is centered beyond the plane of convergence at a distance from it of about half the camera distance. We can assume that a 2-in. focal length gives the best perspective relationship for the better viewing positions in an average theater. This means that $p_o/p = 2/f$ where f is in inches. Using $a = {}^1/_2\, p$ and $G = 1$, we find that Eq. (31) becomes

$$b = e\,\frac{3f}{4 + f} \tag{32}$$

which is an excellent working equation for medium shots.

For telephoto shots, the depth a may be very small compared with the distances p and p_o. With these shots we want no giantizing effect so that $G = 1$. Therefore Eq. (31) becomes approximately

$$b = e(f/2) \tag{33}$$

On the other hand, where the field of interest extends from the plane of convergence back to very distant backgrounds, the value of a will be very large compared with p or p_o. The factor $(p + a)/(p_o + a)$ then becomes very nearly one, and (since again G is unity), the interaxial spacing is given by

$$b = e \tag{34}$$

regardless of the focal length of the lens.

For close-ups, it is more satisfactory to specify the depth of the field of interest in terms of the height of the projected picture. This is the usual way of specifying the close-up; that is, it is a half-figure, bust or head, referring to the portion of the figure that fills the screen. The factor G is then also a function of the magnification and a simple expression for the interaxial spacing can be obtained. For example, assume that the depth of field of interest a is 5/6 of the picture height, h. Then for standard apertures 0.600 in. in height, $p = (h/0.6)f$, and since $p_o = (2/f)p$, we find that $p_o = h/0.3$. Substituting these values in Eq. (31) gives

$$b = \frac{f + 0.5}{G} \tag{35}$$

as a very usable equation for close-up photography provided suitable values of the factor G are known. Incidentally, this equation approximates the values of Eq. (32) for medium shots closely enough for use with lenses having focal lengths of 3 in. or less. Results with it have verified its usefulness under the specified conditions.

The "giantizing" factor G in Eq. (35) is found to be a function of magnification only, and was evaluated on the basis of a series of actual tests. A plot of the results is given in Fig. 10.

Incidentally the factor G can be used for calculating shots which must deliberately be made to appear giantized or miniaturized. For example, if a scaled-down model with a scale factor of 8 is to be photographed to appear full sized, the factor G in Eq. (31) should be 8. On the other hand, if a model

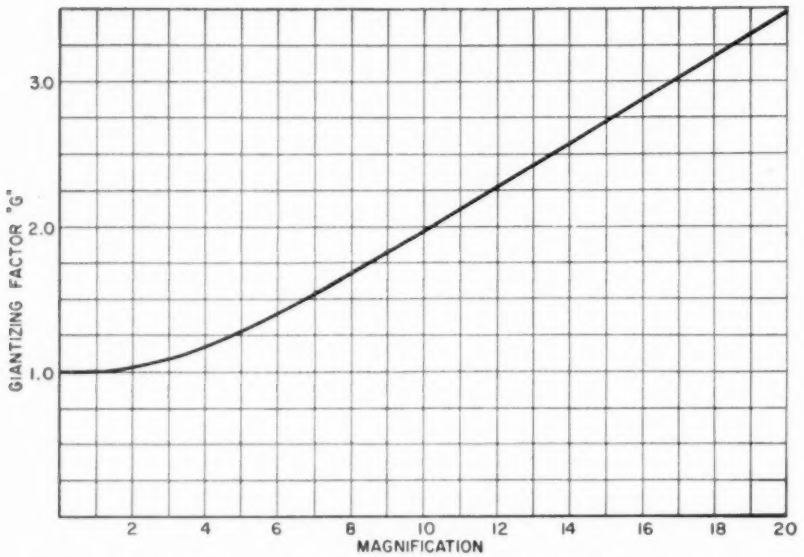

Fig. 10. Relationship between the giantizing factor "*G*" and magnification. The factor "*G*" is that required in equation (35), and the magnification is that defined by equation (3).

is to appear 1/3 actual size in the projected picture, G should be 1/3. Actually the problem is not quite as simple as this, for additional psychological factors, and "showman's license" must be taken into account. However, this formulation will provide a starting point from which tests can be made to determine the most satisfactory settings.

III. DETERMINATION OF FAR POINTS AND BACKGROUND DIVERGENCE

As mentioned previously, another natural assumption which has been made by many authorities in the field of stereoscopic projection is that the lines of sight must not diverge for any homologous point pairs. It is felt that such divergence would make them appear at a distance "beyond infinity," which of course could not happen. Fundamentally, this assumption is closely related to, and in fact is based on, the assumption that the eyes can in some way detect the absolute directions of these lines of sight. The Luneburg transformation (Eq. (25)), incidentally, handles such divergences, as long as they are quite small, without difficulty, indicating that perhaps fusion can take place and objects can be seen in correct proportion, even though the lines of sight do diverge slightly. Experience shows that this indication is correct. The eyes actually cannot detect slight divergences in the lines of sight, and while these are admittedly not encountered in natural seeing, nevertheless satisfactory fusion of images can take place if the amount of divergence is kept within reasonable limits.

Restrictions If No Divergence Is Allowed

Let us first consider the limitations

imposed upon the photography of stereoscopic pictures by the restriction that no divergence of the lines of sight to any homologous point pairs can take place in the viewing of projected pictures. This is equivalent to saying that no w' of the kind shown in Fig. 2 can exceed 2.5 in. or the normal interocular distance. From Eq. (3) then, this limits the corresponding value of w for objects infinitely far from the camera to not more than $2.5/m$. At an infinite distance, the lines of sight to the camera lenses will be parallel and therefore the maximum spacing of the lenses will be

$$b = e/m = \frac{Wsep}{upf} \qquad (36)$$

which (except for the different notation) is the well known "Wed/sf" formula given by Rule,[7] Norling[8] and others.

Projection on theater screens requires the use of values of m of the order of 3 or more for most useful shots. This means that for screens 24 ft wide, interaxial spacings must be of the order of 3/4 in. or less. Such small spacings cannot be obtained with 35mm cameras without the use of beam-splitting devices, with their resultant loss of light. Furthermore, they give rise to "cardboarding" effects which are always undesirable.

How Much Divergence Can Be Tolerated?

Fortunately, it appears possible to allow some divergence of the lines of sight. Fry and Kent[9] have shown that stereo-acuity is fully as sharp with slight divergence as with an equivalent amount of convergence. In fact, clear single vision seems to be possible for most observers up to total divergence angles of greater than 5° (i.e., 2.5° for each eye). There is some evidence that eyes at rest apparently turn out approximately 1/2° each, indicating that there should be no physical discomfort even should the eyes turn outward to follow the diverging lines of sight. Finally, actual tests with pictures which have been projected so that a divergence in the lines of sight is required show that such pictures can be fused easily by most observers. They look perfectly natural, and no unusual strain is set up provided always that certain definitely specified limits are not exceeded.

On the basis of these considerations, the assumption has been made that a divergence of the lines of sight of 1/2° for each eye, or a total of 1° negative bipolar parallax could be allowed for an observer 40 ft in front of a screen 24 ft wide. Such a screen with standard aspect ratio, would be approximately 18 ft high. Since it can safely be assumed that no screen will ever be observed at a distance less than its height, a minimum viewing distance can be taken as 18 (or 20) ft. This will give a divergence of slightly over 1° for each eye which is still less than half of what can be safely tolerated by most observers.

The Maximum Separation Used in the Research Council System

On the basis of the above assumption, photography for a screen 24 ft wide should be such that no homologous point pairs are separated at the screen more than 480 × tan 1/2°, or 4.19 in. for each eye plus the interocular distance of 2.50 in. or a total of 10.88 in. The Research Council system therefore recommends a maximum separation of 11 in. for such point pairs.

This value will allow the photography of infinitely distant points with a "reduced" magnification value of 4.4, instead of 1.0 as allowed under the condition of no divergence. This in turn increases the maximum allowable value of b to 4.4 times the value given by Eq. (36). The manner in which this allows much more practical camera settings is shown in Table III.

Table III clearly shows the desirability, and in fact the necessity, of allowing a small amount of divergence. With the amount specified, it is seen

Table III. Comparisons of Camera Settings When No Divergence Is Used and When Slight Divergence Is Allowed.

Condition		Setting specified by Eq. (36)	Setting specified by Research Council
f = 2 in.	Distance to object (plane of convergence) is 10 ft. Interaxial	0.43 in.	1.9 in.
f = 3 in.	Waist figure close-up. Interaxial	0.29 in.	2.1 in.
f = 2 in.	Distance to plane of convergence is 10 ft. Distance from plane to farthest point in set (interaxial −2.5 in.) should not exceed	2 ft-1 in.	31 ft
Same but with interaxial spacing recommended in first line		6 ft-8 in.	Infinite
f = 2 in.	Distance from camera to plane of convergence if infinitely distant points are also in scene, using 2.5 in. interaxial	58 ft-4 in.	13 ft-3 in.

Table IV. Maximum Separation (in inches) of Homologous Point Pairs on Screens of Different Widths for Different Aspect Ratios.

Width of screen, ft	Screen magnification,* M_s	Aspect ratios (width/height) 4/3 (standard)	5/3	7/4	1.85/1	2/1	7/3	8/3
15	218	7.9	6.8	6.6	6.4	6.1	5.6	5.2
18	262	9.0	7.7	7.4	7.2	6.8	6.2	5.7
21	306	10.0	8.5	8.2	7.9	7.5	6.8	6.2
24	350	11.0	9.4	9.0	8.7	8.2	7.4	6.8
27	393	12.2	10.3	9.9	9.5	9.0	8.0	7.3
30	437	13.2	11.1	10.7	10.2	9.7	8.7	7.9
35	509	15.1	12.5	12.1	11.6	10.9	9.7	8.8
40	582	16.8	14.0	13.4	12.8	12.1	10.7	9.7
45	655	18.6	15.4	14.8	14.1	13.2	11.7	10.6
50	727	20.5	16.8	16.2	15.4	14.5	12.7	11.5

* This assumes that aperture has standard width.

that relationships between camera and set can be kept about as they now are for "flat" photography.

Photography For Wide Screens

When photography is for wider screens, care must be used that the divergence which has been specified is not exceeded. Assuming that no screens will be viewed from less than their height, and that at this minimum viewing distance the divergence of the lines of sight should not exceed 1° for each eye, Table IV gives the maximum separation of homologous point pairs for various screen widths and aspect ratios.

IV. DETERMINATION OF NEAR POINTS

At least three important factors must be given consideration when subject matter is made to appear between the screen and the observer. One of these, of course, is the "window" which forms the transition between the projected picture and the theater. Successful composition must take into account its effect in each of the three dimensions just as the effect of the masking or frame must be taken into consideration in "flat" pictures. A second factor can be termed "psychological" distortion, for it is caused by the recognition of relationships between the projected images and reference points in the theater and could be largely eliminated by projection in a perfectly dark, empty room. The third factor is the unnatural relationship which must exist between the convergence of the eyes and their "accommodation" or focus as they look at an image point which may be relatively near, yet must keep focused on the screen plane.

The Window

The stereoscopic window is provided by the limiting aperture of the stereotransmission system. Since this is usually the masking at the screen, and this masking will provide the same aperture for both pictures, the window is usually at the screen plane. This is not necessary, however, for several more or less successful arrangements have been tried which project a "window in space" whose position is some distance in front of the screen. Such a positioning has several advantages as will be seen from the ensuing discussion.

With proper alignment of photographic and principal axes, the equivalent positions of the "window" in the object space will coincide at the plane of convergence when the window is formed by the projector apertures (or screen masking). This is shown in Fig. 11, which shows also the field of view of each of the two camera lenses, and of each eye of an observer standing in the position from which the picture apparently is taken (according to the perspective given by the lens focal length and viewing conditions).

It is at once apparent that the fields of view of the camera lenses and of the observer's eyes do not match. Therefore there will be a slightly unnatural effect near the edges of the picture. Vertical objects which appear in one of the two pictures but not in the other will be particularly confusing. The effect of such objects is even worse if they are supposed to be forescreen, as then by all conditions of natural vision they should be visible to both eyes.

The window, of course, will cut off any scenic elements which extend beyond it, even though such elements appear forewindow. In other words, if any scenic elements such as tree limbs, table tops or the like, extend out of the window, caution must be used that they are not cut off and left "dangling" in space over the heads of the audience.

Psychological Distortion

The photographic system discussed here is based upon the assumption that dimensional proportions will appear the same to an observer in the theater as if he had actually been in the position from which the picture appears to have been taken. In most cases therefore, he must be made to feel that he is actually nearer the scene than his distance from the screen. Unless he can do so, there will be a definite loss of "intimacy" and much of the dramatic effect otherwise possible from the presentation will be lost.

In order to make the observer feel that he is close to the scene, the geometric depth has been deliberately increased so that at screen distance the projected pictures will present the same "see-around" as the real objects

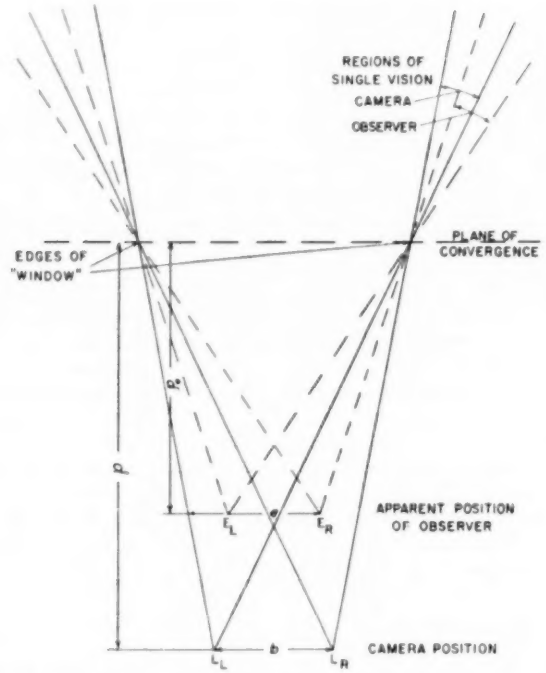

Fig. 11. Fields of view of camera and observer when window is at screen plane. As in all of these illustrations, angles must necessarily be greatly exaggerated.

would at much shorter viewing distances. The results are satisfactory, provided no clue is given as to the actual distances to the projected image points. When these points are behind the screen there is little likelihood that any external reference points can spoil the effect. However, as soon as they are brought forescreen, any objects which are visible in the theater may serve as reference points to give the observer a clue as to the actual distances to the projected images. For example, if the plane of convergence in a side view of an actor coincides with the side of his face, so that his shoulder and arm are forescreen, these may quite easily come out as far as halfway to the observer. Now if they do not come near the side of the screen or any other visible object in the theater, the effect will be quite acceptable. However, if it is noticed that, say, the front edge of the orchestra pit, or the lady with a big hat in the fifth row, are well beyond the closer portions of the image, the entire effect is lost and a definite "stretch" appears.

This effect is particularly noticeable in objects which are intended to come entirely forescreen. If they appear to do so, they will retain their natural proportions, but if for some reason they remain tied back to the screen plane, the distortion will be quite apparent. The reason we speak of this as "psychological" is therefore obvious, for it depends entirely upon the way the image positioning is interpreted by the observer.

The Accommodation-Convergence Relationship

The effects which have just been discussed will at worst cause the projected pictures to be unnatural in appearance and unpleasant to look at. The unnatural accommodation-convergence relationship required in the viewing of far forescreen image points, on the other hand, can cause real discomfort, and in extreme cases may result in pictures which the eyes will refuse to fuse — in other words, which will be seen as doubled.

In natural viewing, the accommodation is subconsciously adjusted to agree with the distance at which the eyes converge, at least for objects in the near and medium viewing distances. As far away as the screen for average viewing distances in the theater, however, changes in accommodation are very small even with large changes in convergence distance, so that little concern need be given this factor when images are at or behind the screen plane. On the other hand, when the image points are well forescreen, the eyes are required to converge on a relatively near point, yet maintain their focus on the distant screen. This means that the reflexive relationship between accommodation and convergence must be broken. Some observers can do this quite easily, others find it much harder, but generally speaking everyone must *learn* to look at forescreen objects in a manner quite different from that used in natural viewing.

It is not difficult for most observers to readjust this relationship as long as they can maintain fusion of the pictures. It does take a little effort, however, and this effort depends almost directly upon the amount of forescreen subject matter there is in proportion to that which is at, or behind the screen plane. It also increases rapidly as the proportional distance out from the screen increases.

Hofstetter[10] has shown that for most observers, fusion can take place with accommodation at distances comparable to those in an average theater, when image points are as close as 30 in. from the observer. Allowing a "factor of safety" of 2 as we did for the separation of background points, and again using a "close" viewing distance of 20 ft or 240 in., we find that most observers will be able to fuse stereoscopic pictures satisfactorily if they do not come closer than $\frac{3}{4}$ of the way out from the screen.

How Far Forescreen Can Image Points Come?

If there is so much difficulty with forescreen or forewindow subject matter, why bring image points forescreen at all? The answer is, of course, that only by doing so can the images be brought close enough to the observer to give the best effects obtainable with this medium. The "stage" between the screen and the observer is much nearer and therefore more "see-able" in many ways than that which extends back from the screen. Furthermore, forescreen subject matter comes out a proportionate distance to *each* observer, so that those in the back seats receive more of the effect — a partial compensation for their added distance from the screen.

On the other hand, most of the difficulties which have been mentioned can be controlled quite satisfactorily by observing a few simple rules, and by following the results of calculations based upon the theory which has already been developed.

For example, we have already seen that any subject matter which is to be viewed for any period of time, or with any clarity, should not come closer than $\frac{3}{4}$ or 0.75 of the way out from the screen. Actually the Research Council recommends use of an "0.8 near point" as the nearest any objects should be brought out. Even at this distance, viewing will be difficult and "stretch" will be apparent. Therefore for sustained pleasant viewing a closer limit is needed.

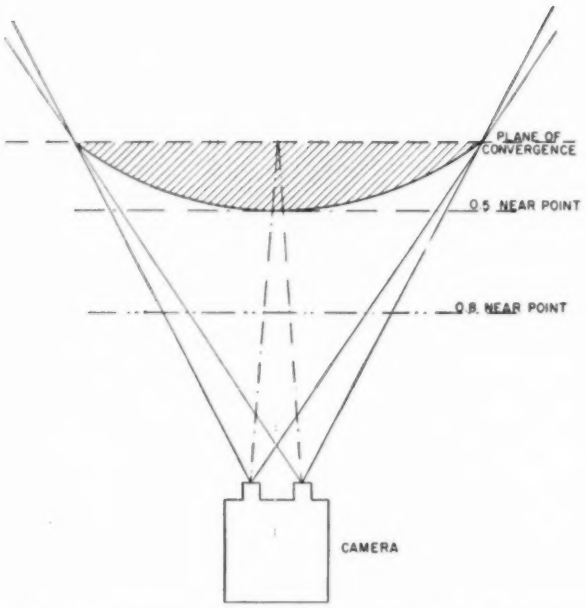

Fig. 12. Forescreen action area where window is at screen plane. Shaded area shows region in which forescreen action can take place without distortion or difficulties with the window edges. Some care must be given that forescreen subject matter near top at center is not cut off unnaturally.

Rule[7] recommended that no objects be brought closer than halfway from screen to observer, that is to the "0.5 near point." Experience has shown this to be a very sound recommendation, because within this limit psychological distortion seldom gives any trouble, and no noticeable strain occurs from accommodation-convergence breakdown. Under some conditions, with suitable subject matter, it is possible to have sustained, comfortable viewing at slightly greater ratios. This is particularly true if a forescreen window is used as discussed later. However, as a general recommendation, the 0.5 near point provides a safe limit which will insure satisfactory results.

Recommended Forescreen Action Areas

We now have the information needed to recommend suitable areas between the plane of convergence and the camera in which action can take place, or objects can be placed, and still give pleasing results when the pictures are projected on theater screens.

In the first place, we must avoid having forescreen, or rather forewindow subject matter near the sides of the picture. Except for the very near seats, the lower edge of the window seems to give but little trouble in this respect, and objects can be brought forward in the center of the scene without the distracting effects found at the sides. Attention must be given the top edge, however, for if it cuts off objects which should appear to project into the auditorium, the desired effect will certainly be lost.

When the screen masking forms the

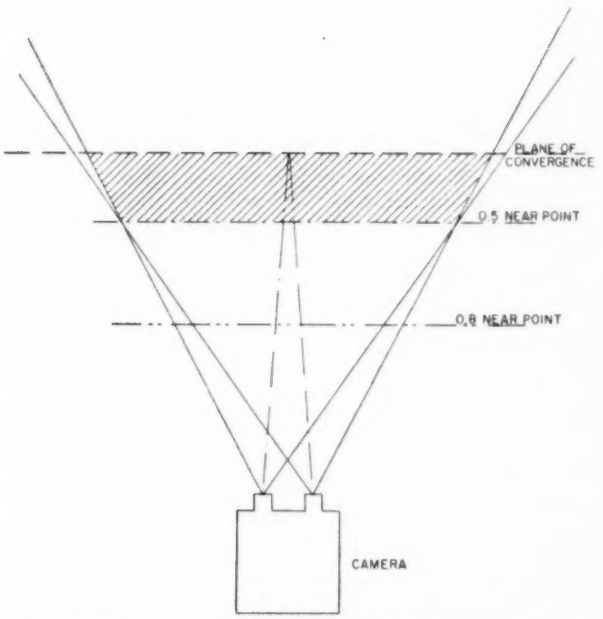

Fig. 13. Forescreen action area where a forescreen window is used at the 0.5 near point. Shaded area shows region in which forescreen action can take place without distortion and without difficulties with window edges.

window, the recommendation is that the main action in front of the camera be confined within a curved line as shown in Fig. 12, with the center at the 0.5 near point, and the sides arcing back to the plane of convergence at the edges of the field of view. Projected objects, and other subject matter, used to provide special effects, can be brought out to the 0.8 near point provided they are not held there for too long, and provided of course that the inevitable distortion will not be undesirable.

When a forescreen window can be used, the foreground action area can take the form shown in Fig. 13. There is some increase in this area over that shown in Fig. 12, but this may be lost by the decrease in aperture size, and therefore in field of view, required to provide the window.

Use of the "Near Point" Reference Lines

In brief then, it is desirable to establish on the set, two "near point" reference lines. One of these will be at those positions which will appear to be 0.5 of the way from the screen to each observer, and this will be the limit of any action or subject matter which is to be looked at for more than a few seconds at a time, or which is to be free from what we have termed psychological distortion. The other reference line should be at the 0.8 near point, and nothing which is to be seen clearly should be allowed to come closer to the camera than this reference line. If some special effect requires that objects do come closer than this, it must be remembered that they will be very hard to look at and for many observers will appear only as indistinct blurs.

V. CONCLUSIONS CONCERNING THE PRACTICABILITY OF THIS SYSTEM

(a) The system proposed by the Research Council is comparatively simple and straightforward. To one unacquainted with it, it may at first seem to be quite otherwise, but this is only because so many more factors can be taken into consideration and given proper treatment than can be treated in other systems.

(b) There is plenty of allowance for psychological factors and for judgment on the part of the operator. For example, the factor G is determined upon psychological principles. The best values to use for a and p_0 are a matter of judgment and experience. Nevertheless, once these factors have been determined properly, selection of a suitable interaxial distance is a simple, straightforward calculation.

(c) The system is flexible enough for use with any kind of shot. Intelligent treatment can be given close-ups, long telephoto shots, scenic vistas having great depth, and all the varied shots constantly occurring in everyday shooting. Provision is also made for taking good miniature shots and other special effects, and for suitably positioning titles, animated cartoons and similar subject matter which is to appear in three dimensions.

(d) The system has been proved in practice. Several critical tests have been made comparing this system with other proposed bases for calculating these settings. In each case the Research Council proposals were demonstrated as much superior in their ability to give pictures which were natural and pleasing to the eye and which avoided most of the difficult seeing conditions so often encountered in three-dimensional pictures.

This system therefore takes into account the basic principles of physiological optics, and uses these to establish the best way of taking stereoscopic pictures so that they will appear as natural as possible when projected in the theater and viewed from various viewing positions. In so doing, it uses principles which are known to give good results and which can be depended upon not to strain the eyes. Leading eye specialists have pointed out that the viewing of properly photographed three-dimensional pictures can actually be helpful to the eyes. We submit that pictures taken in accordance with the principles set forth here will have a maximum of third-dimensional effect, will have a pleasing balance between perspective and binocular depth, and will above all be easy and pleasing to look at.

References

1. Raymond Spottiswoode, N. L. Spottiswoode and Charles Smith, "Basic principles of the three-dimensional film," *Jour. SMPTE, 59:* 249–286, Oct. 1952.
2. Lord Charnwood, *An Essay on Binocular Vision,* Hatton Press Ltd., London, 1950.
3. Kenneth N. Ogle, *Researches in Binocular Vision,* W. B. Saunders Co., Philadelphia, 1950. Ch. 12.
4. Rudolph K. Luneburg, "The metric of binocular visual space," *J. Opt. Soc. Am., 40:* 627–642, Oct. 1950.
5. Walter C. Michels and Harry Helson, "Man as a meter," *Physics Today, 6:* 4–7, Aug. 1953.
6. Rudolph K. Luneburg, *Mathematical Analysis of Binocular Vision,* Princeton University Press, 1947.
7. John T. Rule, "The geometry of stereoscopic projection," *J. Opt. Soc. Am., 31:* 325–334, Apr. 1941.
8. John S. Norling, "The stereoscopic art," *Jour. SMPTE, 60:* 268–308, Mar. 1953.
9. G. A. Fry and P. R. Kent, "The effects of base-in and base-out prisms on stereo-acuity," *Am. J. Optom. Monograph, 4:* Dec. 1944.
10. H. W. Hofstetter, "Zone of clear single binocular vision," *Am. J. Optom. Monograph, 10:* Aug. 1945.

Optical Techniques for Fluid Flow

By NORMAN F. BARNES

In flow studies of liquids and gases, the velocity, pressure, density and temperature of the moving fluid can be obtained through the use of schlieren, shadowgraph and interferometer techniques. A basic optical and photographic description is given of the three systems, and a fundamental application comparison is made.

IN THE STUDY of the flow of fluids, both liquids and gases, it is necessary to know the distribution of velocity, pressure, density or temperature of the moving fluid. In many cases it is possible to obtain much information by passing a beam of light through the flow and observing the effect of the fluid upon the light beam. The variations in density throughout the flow produce corresponding changes in the index of refraction of the fluid, these in turn causing variations in the beam of light. These latter variations can then be made visible on a screen or recorded on a photographic plate.

Though optical methods are sensitive only to density variations, the related flow characteristics of velocity, pressure and temperature can usually be calculated through the application of the laws of fluid mechanics, perhaps supplemented by certain nonoptical measurements to define the state of the fluid. There are three main advantages of an optical approach to the study of fluid flow: (1) the light will not distort or retard the flow; (2) measurements can be made over the entire field simultaneously; and (3) the measurements are free from inertia effects, such as are present if smoke or other particles are induced into the flow to make the characteristics of the latter visible. It becomes the object of the optical analysis, then, to analyze the variations imparted to the beam of light in order to find the corresponding changes in density of the fluid which produced such variations.

In Fig. 1, a light ray is shown entering a disturbing medium. After it emerges, it continues toward the screen, striki g it at a point P′ rather than at the point P where it would have arrived had not the disturbance been present. The angle between the original direction of the light ray and its final direction after passing through the disturbance is represented by angle A. Since the velocity of light changes with the density of the medium in which it travels, the time of arrival of the ray at point P (time t) is different from the arrival time at point P′ (time t′). There are, therefore, three

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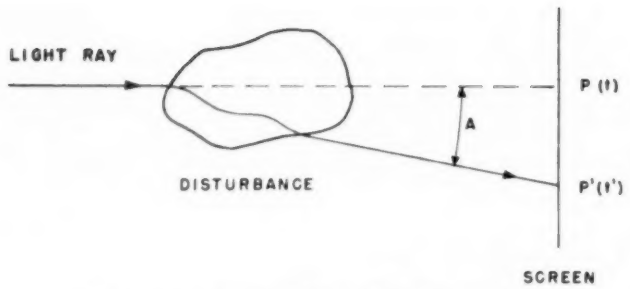

Fig. 1. Light ray entering a disturbing medium.

Fig. 2. Shadowgraph system.

variations or results of the disturbance which can be used as the basis of optical measurement. These are the displacement of point P to P′, the deflection or angle A and the difference in arrival time $t' - t$. Each of these three variations forms the basis of a different type of optical measurement. Thus, the shadowgraph method records the displacement of the ray while the schlieren method is based on the angular deflection of the ray. Finally, the interferometer method is based on the difference in arrival time between the disturbed and undisturbed rays. Each of these methods will be described, showing the type of equipment used and the nature of the results produced.

Figure 2 illustrates a shadowgraph system. A point source of light such as a spark gap illuminates a test area, the light then being allowed to fall upon a screen or photographic plate. If the rays of light do not undergo any deviation in the test area, the screen will be uniformly illuminated. However, if a disturbance is produced, the rays of light which are affected will undergo a deviation causing a corresponding change in the illumination on the screen. Thus, referring to Fig. 3, the rays which normally would have reached the screen at area A have been refracted to area B, producing a lowering of illumination at A and an increase at B.

Since the angular deviations of the rays are proportional to the first derivative of density perpendicular to the ray of light, and since the variation of illumination on the screen is proportional to the derivative of the deviation, the final variation of the light on the screen is proportional to the second derivative of the density in the disturbance. Consequently, the shadowgraph method is most useful in the study of abrupt variations in density such as those which occur in the presence of shock waves. For slow and continuous variations in density, the shadowgraph system becomes insensitive.

A spark gap, using either zinc or magnesium electrodes, has proved to be useful for shadowgraph photography. The primary reason for this is that the circuit characteristics for a spark discharge are such that they permit an extremely short time duration of the flash as compared with that produced by dis-

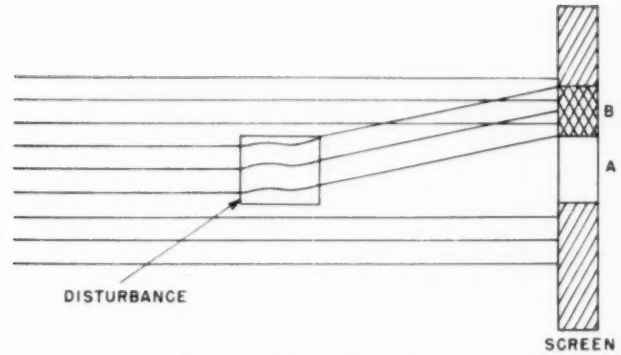

Fig. 3. Shadowgraph effect.

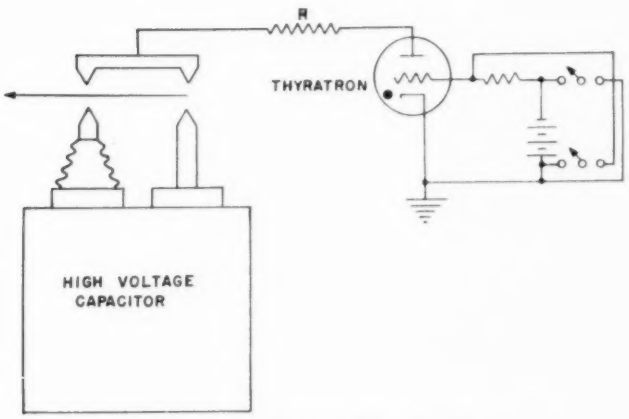

Fig. 4. Shadowgraph spark source.

charge lamps. By using the spark source shown in Fig. 4 effective photographic exposure times of 0.2 μsec have been made. That such an extremely short time could be obtained is due largely to keeping the inductance of the discharge circuit to an absolute minimum. Prior to the discharge the double-pointed electrode shown above the capacitor is allowed to "float" electrically, the gap separations being such that the high-voltage capacitor will not discharge itself. When the double-pole, double-throw switch is thrown, a positive voltage is applied to the thyratron tube so that it becomes conducting, therefore lowering the double-pointed electrode to ground potential. A spark then jumps from the high-voltage terminal to this electrode, thereby raising its potential to the maximum and thus allowing the spark to jump to the ground terminal on the capacitor. The two spark gaps are lined up in the direction of the arrow, producing the effect of a single source as seen from the disturbance. The entire discharge circuit consists of only several inches of heavy conductors.

Fig. 5. Bullet discharged from the muzzle of a gun.

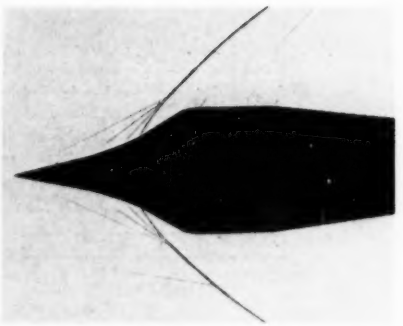

Fig. 6. Shadowgraph picture of supersonic flow past a multiple shock diffuser central body for a Mach number of 2.7

The results which have been obtained with the General Electric spark unit are illustrated in Fig. 5. Here the discharge energy was obtained from a 0.12 μf (microfarad), low inductance capacitor charged to 10,000 v. The picture shows a bullet being discharged from the muzzle of a gun. The many curved lines in the picture are sound waves generated when the compressed gases expand from the muzzle. The bullet is centered in the air that it pushes out of the barrel by its piston action. The expanding, turbulent gas behind the bullet gives it its acceleration.

The spark gap was placed approximately 15 ft to one side and perpendicular to the path of the bullet, while the film was placed at a distance of 18 in. to the other side and parallel to the bullet path.

Figure 6 shows a shadowgraph picture of supersonic flow past a multiple shock diffuser central body, for a Mach number of 2.7 as photographed by the NACA (National Advisory Committee on Aeronautics) laboratories.

Although the sensitivity of a shadowgraph system increases directly with the distance between the disturbance and the screen or photographic plate, a point is soon reached beyond which the resolution of the image rapidly deteriorates; thus, a compromise must be made between sensitivity and image quality. The size of the discharge spark will also have an important bearing upon the image quality of the shadowgraph picture. If a relatively large spark is used, it will have to be placed farther away from the disturbance in order to act effectively as a point source. Good results can be obtained using photographic films having moderate or high speeds. In general the extremely short exposure time produces a lower-than-normal contrast upon development so that it is advisable to use higher contrast developers with times ranging from normal to three times normal.

Figure 7 is an NACA shadowgraph picture of rather unusual interest showing the shock-wave formation on a P51 airplane in flight.[55] Figure 8 shows how this picture was produced using the parallel rays from the sun as the light source. The increasing strength of the shock wave going nearer to the upper surface of the airfoil acts as a prism to deflect the rays of light as shown.

While the great advantage of the shadowgraph method is the extremely simple arrangement which requires no lenses or mirrors, the system is far too insensitive for many applications. A small displacement which would be insignifi-

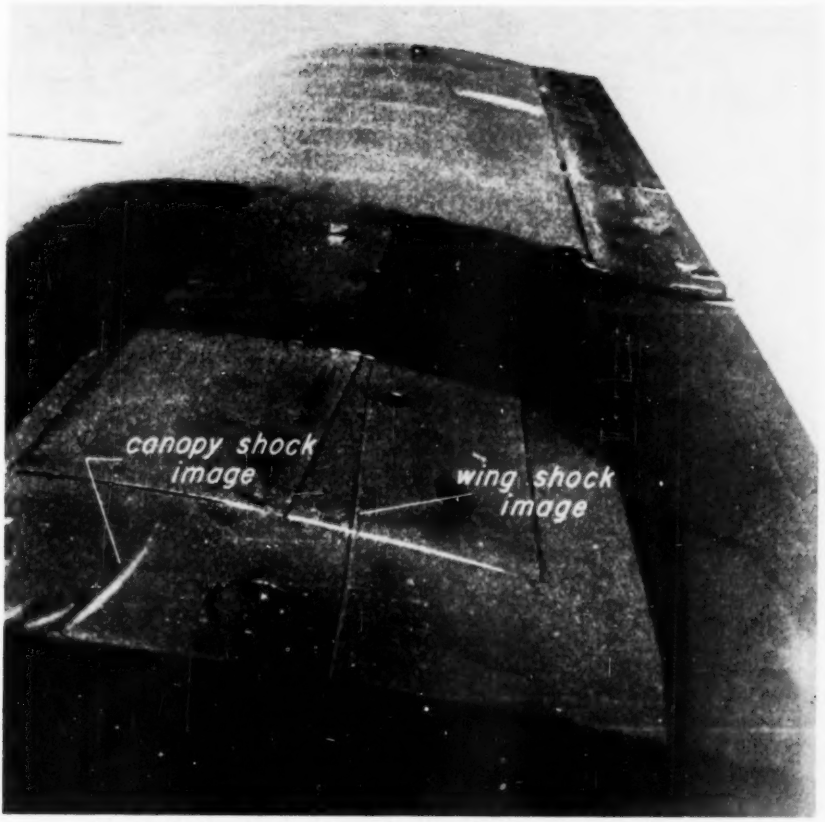

Fig. 7. Shadowgraph picture showing shock-wave formation on a P51 airplane in flight.

cant in a shadowgraph system could produce a very noticeable effect in a schlieren system. The operation of the schlieren method can best be described with reference to Fig. 9. Light from an illuminated pinhole or slit S is allowed to fall upon lens L1 and be converged to the image point at P. A lens L2 is used to focus upon the screen the striation or disturbances produced in the flow placed immediately to the right of lens L1. A knife edge E is moved laterally across the image point until all the rays passing through that image are obscured. The field as viewed upon the screen will then be uniformly dark. If a light ray in passing through the disturbance is refracted upward, this ray will no longer pass through the image point P but will travel above it. Hence this ray will not be obscured by the knife edge but will pass on to the screen, illuminating a point corresponding to the location of that particular part of the disturbance. Thus, for every point in the disturbance for which a similar refraction takes place, there will be a corresponding point illuminated on the viewing screen. The composite of all such points forms the image of the phenomenon to be investigated.

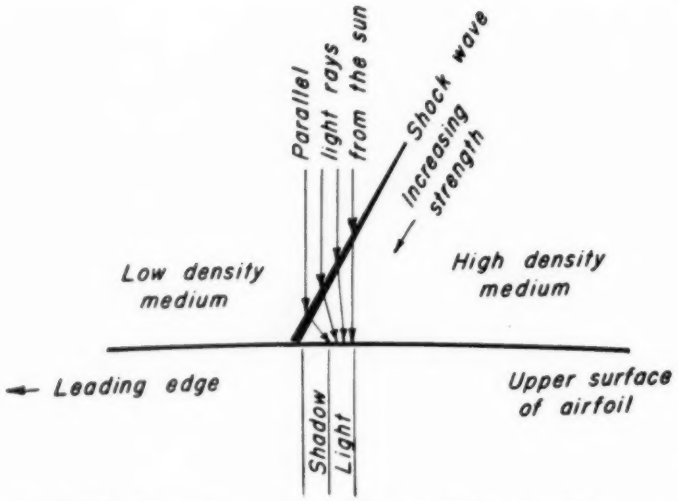

Fig. 8. Chordwise cross section showing production of a shock wave using parallel rays of the sun as a light source.

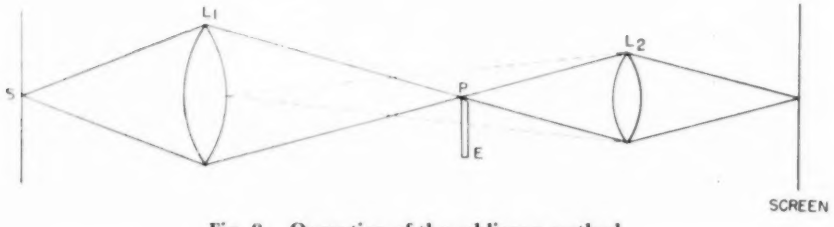

Fig. 9. Operation of the schlieren method.

If the bending in the disturbance is downward the rays will be caught by the knife edge, and the corresponding points on the viewing screen will be dark. In making the lateral adjustment of the knife edge when no disturbance is present, it is desirable to allow some of the rays to pass over the knife edge in order to produce a uniformly low background illumination. The presence of this background makes it possible to see more clearly in silhouette form the objects used in producing the air-flow phenomena. Thus, referring to Fig. 10, a downward deflection of rays darkens the screen while an upward deflection increases the screen illumination.

The field lenses used in the schlieren systems must be well corrected lenses, particularly from the standpoint of spherical aberration. Otherwise, it will not be possible to obtain a uniform brightness across the field projected upon the viewing screen. Also, if large amounts of chromatic aberration are present, the striation image on the viewing screen will not be sharp. The glass of the lenses must be of the finest optical quality and free from scratches so that the lenses will be striation free. Otherwise, any striae in the field lenses will be superimposed upon those which are being investigated.

If a large diameter field is required, it

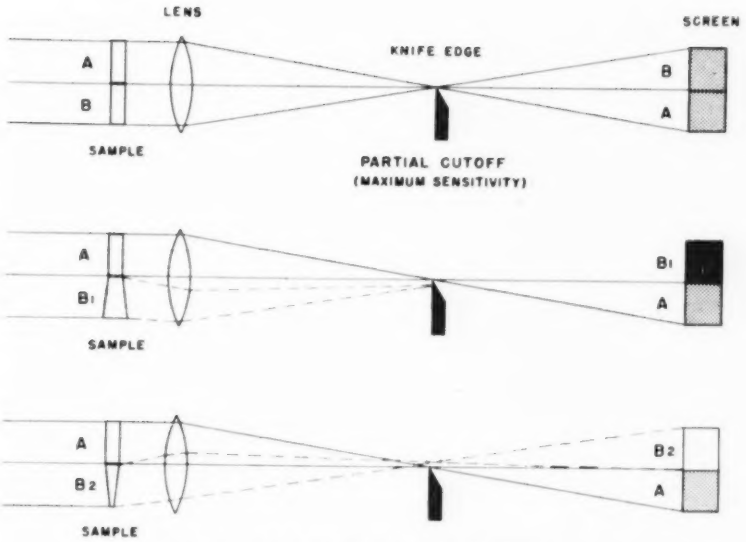

Fig. 10. Schlieren knife edge adjustment.

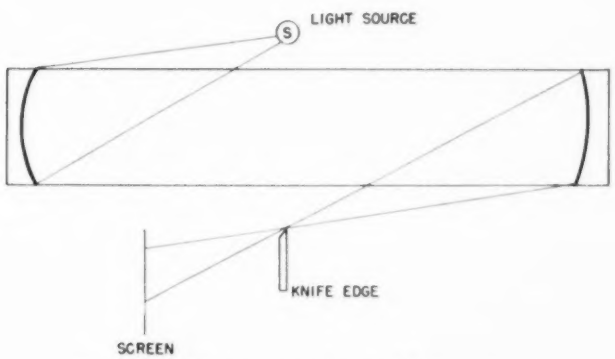

Fig. 11. Double concave mirror schlieren system.

is exceedingly difficult, if not practically impossible, to obtain well-corrected lenses. For that reason it is highly desirable to use concave mirrors in place of the lenses. The use of such mirrors has many advantages. Since first-surface mirrors are used, the optical quality of the glass does not affect the striation field. Furthermore, chromatic aberration is eliminated. Since the mirror surface can be parabolized, it is possible to obtain large mirrors which are well corrected for spherical aberration.

The double concave-mirror system shown in Fig. 11 has proved to be most satisfactory for a wide variety of applications.[178] Here the light passing through the investigation region has

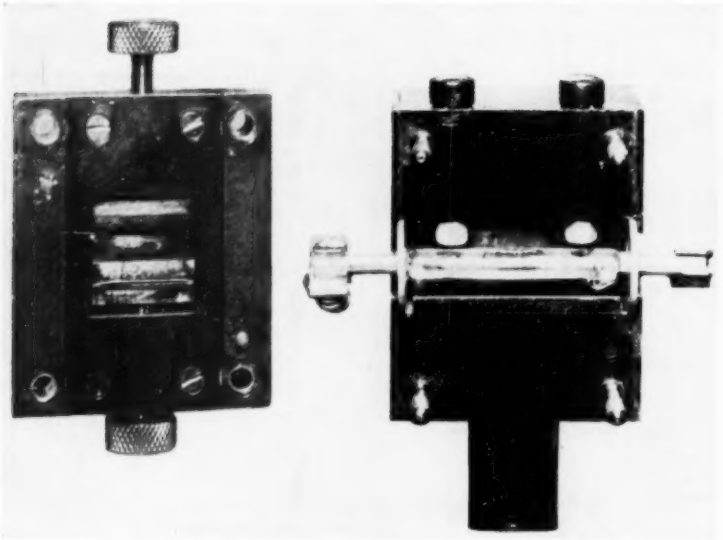

Fig. 12. Mazda Type B-H6 lamp with its air-cooling nozzle.

been made parallel by the first parabolic mirror. Since the sensitivity of the system is independent of the location of the disturbance between the two parabolic mirrors, one can simultaneously use the second parabolic mirror to focus the disturbance upon the screen as well as to converge the light to the source image point at the knife edge. However, because of aberrations of the system, a sharper image will be produced on the screen if a lens is used behind the knife edge for focusing purposes. In order that the system be effectively coma free, the light source and the knife edge must be on opposite sides of the common mirror axis. The equality of the angles from the source to the common mirror axis is required in order to avoid coma, while the size of the angles determines the amount of astigmatism which is introduced. Either of these aberrations will cause a poor knife-edge image of the light source, resulting in uneven sensitivity over the field.

One of the most useful light sources for schlieren systems is the Mazda Type B-H6 lamp. This is a 1000-w, high-pressure mercury lamp used with air cooling. A picture of this lamp along with its air-cooling nozzle is shown in Fig. 12. By the nature of the lamp itself this light source is a natural slit source whose dimensions are approximately 1 by 25 mm. For high sensitivity for photographic recording, slits as small as

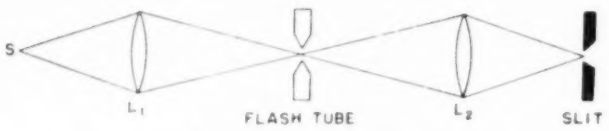

Fig. 13. Schlieren source.

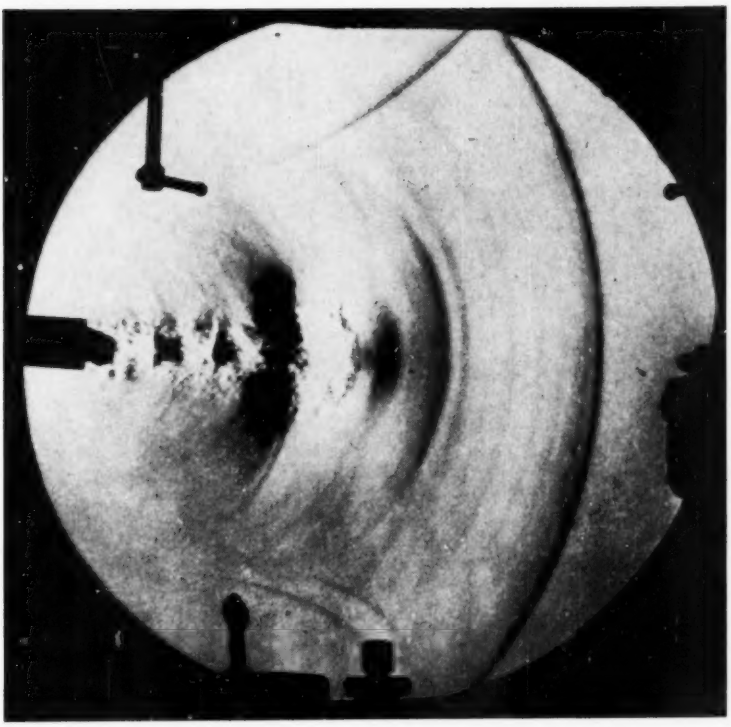

Fig. 14. Schlieren photograph of a jet showing sound waves and the reflection of one from a plate at the top, using a B-H6 lamp as a flash source.

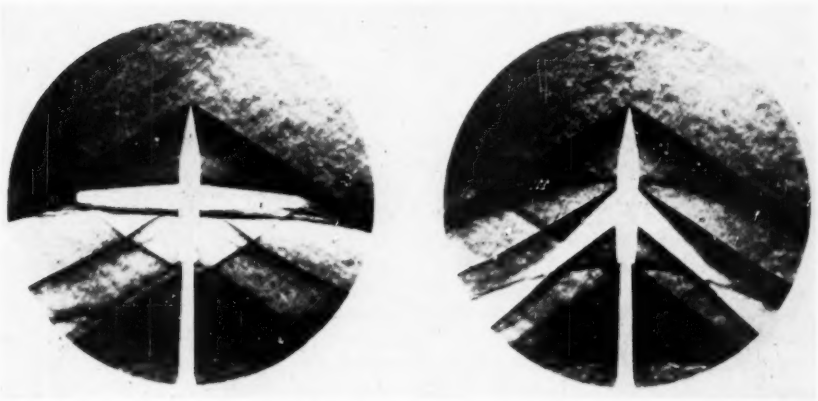

Fig. 15. Schlieren photograph of a jet with wings swept back at a rakish angle.

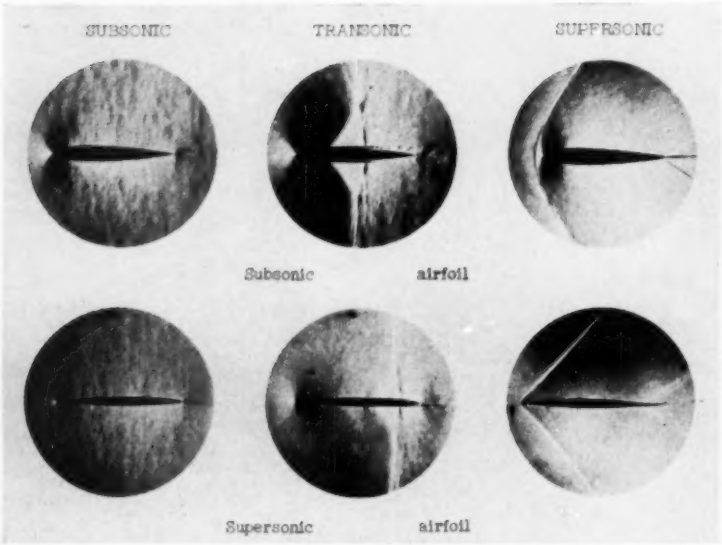

Fig. 16. Aerodynamic phenomena at subsonic, transonic and supersonic speeds for both subsonic and supersonic airfoil.

10 by 40 mils are placed in front of the light source.

The lamp can be operated continuously for visual observation or it can be flashed for taking instantaneous pictures effectively. When a 2-μf capacitor charged to 2000 v is discharged through the lamp, the effective photographic exposure time will be about 3 μsec.

A flashtube such as the FT 230 can also be used as the source of short-duration light. As shown in Fig. 13, light from the discharge gap is focused on a slit, which becomes the effective source for the schlieren system. For continuous observation and alignment purposes, a ribbon-filament, tungsten lamp is placed on the opposite side of the flashtube from the slit and is focused between the electrodes of the flashtube by an auxiliary lens. In this way any adjustment made with the tungsten lamp will be correct for the flashtube.

Figure 14 is a schlieren photograph of a jet, showing sound waves and the reflection of one from a plate at the top, using the B-H6 lamp as a flash source. Further illustration showing the application of schlieren techniques is seen in the NACA photographs of Figs. 15 and 16. The former points out the advantages that can be obtained by sweeping the wings of an airplane back at a rakish angle. With no sweepback, as in the picture at the left, a very intense shock wave is formed, represented by the black region immediately ahead of the wing. When the wing is swept back, the shock wave is also swept back with an accompanying reduction in intensity and hence a reduction in the wing drag. Figure 16 shows aerodynamic phenomena at subsonic, transonic and supersonic speeds for both subsonic and supersonic airfoil. It is interesting to note the tremendous disturbance produced in taking a subsonic airfoil through transonic region to supersonic speeds.

In a schlieren system the deviation of the rays, and hence the screen illumination, is proportional to the first derivative of the density variation. The sensitivity

Fig. 17. Shock wave and the explosive products which come from a dynamite cap.

of the system is proportional to the focal length of the mirrors in the system already described and inversely proportional to the width of the light-source image perpendicular to the knife edge. Optical aberrations, diffraction at the light-source image and the necessity for satisfactory image brightness impose limits upon the possible sensitivity.

High-speed photographic techniques have been developed for the study of transient phenomena in supersonic flow. Bradfield and Fish[56] have developed a repetitive spark light source capable of producing bursts of light for taking up to 250 schlieren photographs at a frequency as high as 16,000 pictures per second. With approximately 20-msec bursts of the high-speed sparks and effective exposure times of 2 to 4 μsec this technique has proved to be very useful in studying nonstationary supersonic flow problems.

A double-flash, high-speed photographic technique has been developed by Edgerton[187] for either the schlieren or shadowgraph study of transient shock waves or rapidly moving objects. Figure 17 shows the shock wave and the explosive products which come from a dynamite cap. The first flash from the spark unit was triggered by the light from the explosion, and the second flash was timed to occur approximately 4 μsec later during which time the shock wave traveled about 0.4 in., corresponding to an average velocity of 8,000 ft/sec. The exposure time is 0.2 μsec.

In the conventional schlieren system the density gradients at all points along the path of a light ray contribute to the resultant image. In a strictly two-dimensional flow no complications arise. However, from practical considerations the flow may be influenced by the boundary layer present on the glass walls as well as by waves reflecting from

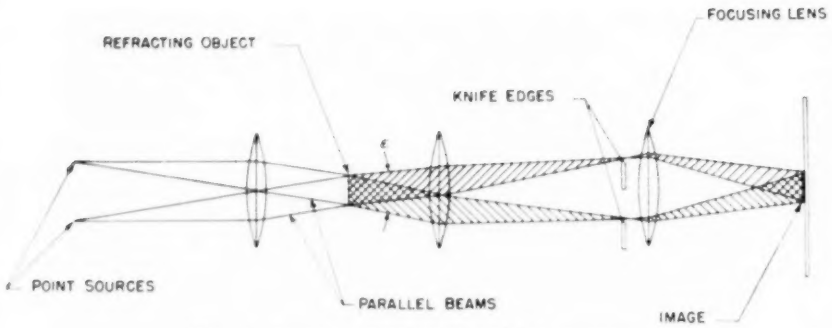

Fig. 18. Focusing effect with multiple sources.

these walls, so that the flow is actually three-dimensional. Consequently, one is forced to try to interpret three-dimensional flow with an apparatus which gives an integrated effect of such phenomena.

In order to obviate such difficulties Kantrowitz and Trimpi[63] have designed a schlieren system which can be focused at any plane in the test section. In order to be able to focus a system in this manner one must have either divergent or convergent light paths, since only by this means can the disturbances at various distances be singled out. Thus, referring to Fig. 18, if two sources and corresponding knife edges are used, the focusing lens will focus just the refracting object on the screen. Any other points will not be superimposed on the screen and will therefore be blurred. In actual practice, fifty or more slits are used along with their corresponding knife edges. Both the source-slit plate and the knife-edge plate are made photographically. Each of these sources and its corresponding knife edge acts as an individual schlieren system. Since the beams will only superimpose for a single plane of the disturbance, two-dimensional investigation of sections of a three-dimensional flow can actually be made. Burton[57, 58] has shown that the use of such grids of pinholes or lines permits the use of large optical fields which are not limited by the physical size of the lenses or mirrors used.

The use of schlieren technique becomes extremely difficult or even useless when the density of the flow is decreased to very low values. It has been shown that certain gases such as nitrogen are capable of emitting light for relatively long periods of time after they have been excited electrically. This phenomenon of persistence of luminescence is referred to as afterglow. Since the intensity of the afterglow increases with increased density of the glowing gas, a method is provided to make the flow disturbances produce their own light so that they may be photographed, the resulting picture being similar to a schlieren photograph in appearance. A schematic diagram of this afterglow equipment as developed by Williams and Benson[79] is shown in Fig. 19. Nitrogen from the supply tank is excited by means of high voltage and then drawn into the test chamber where its glow is photographed. Figure 20 shows the afterglow pattern over a 15°, double-wedge model at a stagnation pressure of 60 mm of mercury and an indicated Mach number of 2.6.

Recalling again the third type of optical measurement dealing with the difference in arrival time between a disturbed and an undisturbed ray, the change in the velocity of the light can easily be measured by comparing the beam of light which has passed through the test section with a similar beam which has passed through a stationary or

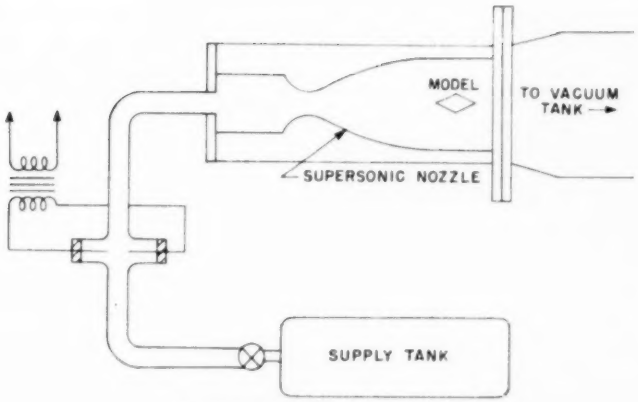

Fig. 19. Afterglow apparatus.

undisturbed field. Since light travels in a wave motion, these two beams of light can then be combined in such a way that the peaks of the waves of each alternately add and subtract to produce interference fringes or lines of alternately weak and strong intensity.

An interferometer consists essentially of a light source, a means of splitting the light into two beams, one of which passes through the test section, a means of recombining the two beams and a screen or camera for observing or recording the patterns. Thus, referring to Fig. 21, the light from the source is made into a beam of parallel rays by lens L1. When these rays reach the beam-splitting plate P1, part of the light is reflected to mirror M1. The part that is transmitted is directed through the test area by means of mirror M2. The two beams are then combined by means of the plate P2, those rays coming from M1 being partially transmitted by the plate and those

Fig. 20. Afterglow pattern over a 16° double-wedge model at a stagnation pressure of 60 mm of mercury and an indicated Mach number of 2.6.

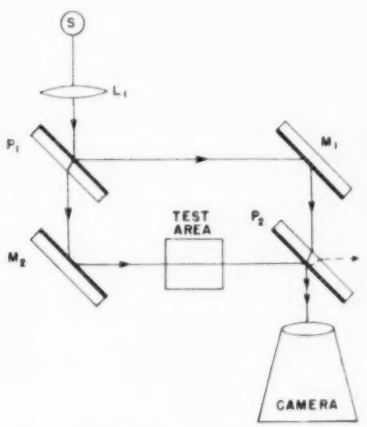

Fig. 21. Mach-Zehnder Interferometer.

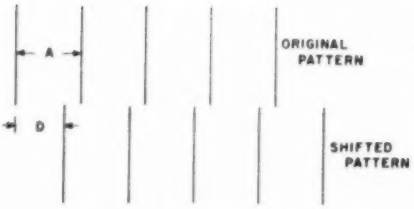

Fig. 22. Interference fringe shift.

coming from M2 being partially reflected. The camera lens then focuses the light upon the photographic plate.

If the optical components are essentially perfect and if the optical path lengths in the two halves of the system are identical over the entire field for no disturbance, then the field of view will be uniformly illuminated and the so-called infinite width fringe will be produced. If one of the beam-splitting plates or one of the mirrors is rotated slightly, interference fringes will be formed whose lines are equidistant and parallel to the axis of rotation of the mirror or plate. At each point where the optical paths in the two halves of the

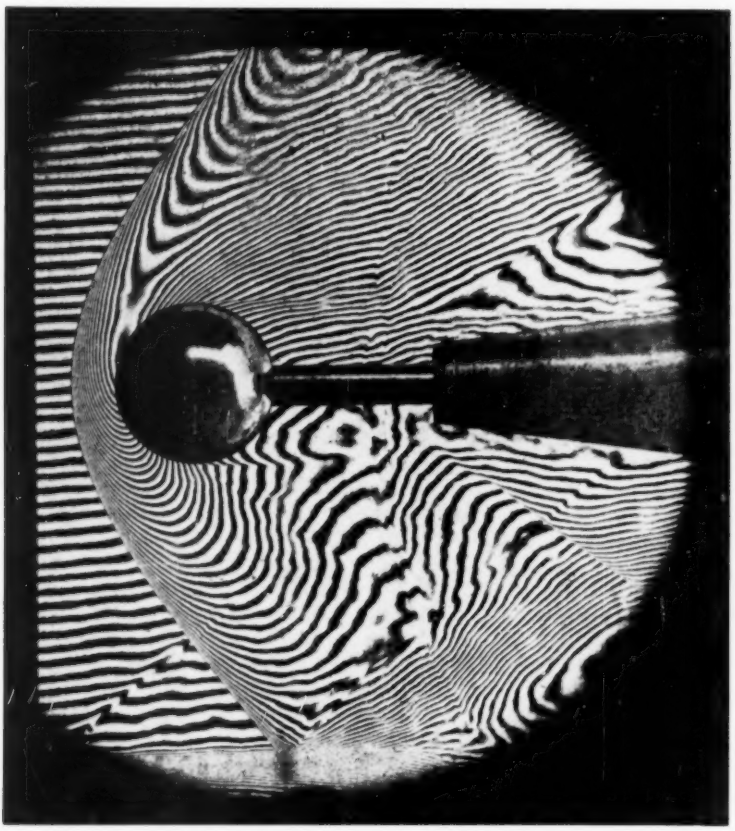

Fig. 23. Interferometer photograph of supersonic flow past a sphere in a free jet at Mach number 1.6.

system differ by an odd number of half-wavelengths of the light used, the two parts of this ray will cancel each other and thereby form a dark zone.

The outstanding characteristic of the interferometric method of analysis is its ability to provide quantitative data. Interference pictures can be evaluated to show the distribution of density throughout an entire flow field. Though the analysis of interference photographs of axially symmetric flow involves rather difficult integral equation calculations[124], the evaluation is relatively simple for two-dimensional flow. In this latter

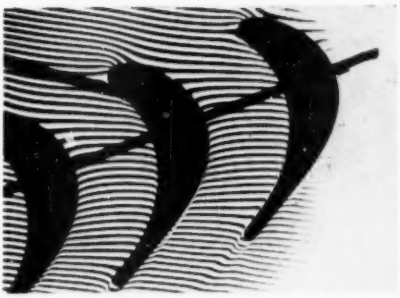

Fig. 24. Flow past cascade of turbine blades.

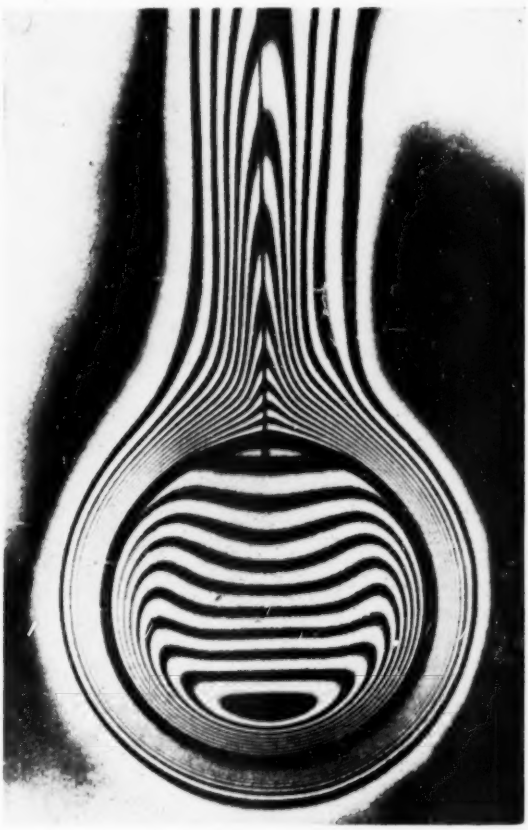

Fig. 25. Interference picture of temperature field formed by natural convection inside and outside a heated, hollow cylinder.

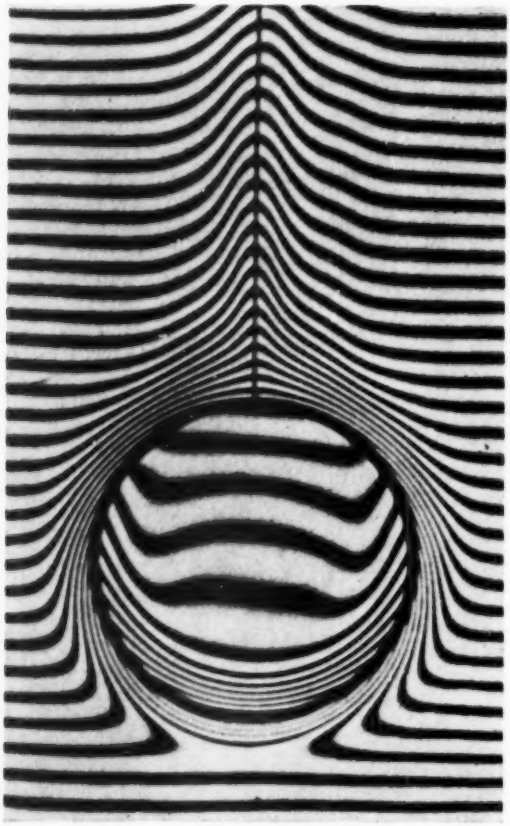

Fig. 26. Interferometer picture showing isothermal lines inside and outside a heated, hollow cylinder.

case, the change in density at a particular point in the flow is directly proportional to the fringe shift from the undisturbed pattern. Thus, referring to Fig. 22, let us assume an undisturbed pattern to have fringes separated by the distance A. If the disturbance then produces a shift D in the fringes, then the value of the corresponding changes in density can be computed so that it is possible to determine the density values throughout the entire field. The density change is directly proportional to the fringe shift D. Means of evaluating interferometer pictures are suggested by Ashkenas and Bryson[148].

Figure 23 is a NACA interference picture of the supersonic flow past a sphere in a free jet (Mach number 1.6). The undisturbed lines are shown at the left of the picture. In the right part of the picture the fringes are distorted by the varying retardation experienced by the light when traveling through the disturbance. Since the interferometer system is sensitive to infinitesimally small deviations of the light path, the method is particularly useful in relatively large regions of continuous and small variations in density. Where these variations are discontinuous or abrupt, interpretation of the picture becomes difficult. The most useful information is obtained when the interference fringes intersect the object sur-

face at right angles. In order to accomplish this result the fringes can be oriented in any direction by proper rotation of the two beam-splitting plates and the two mirrors. An illustration of this, Fig. 24, shows the flow through a cascade of turbine blades.

Figure 25 shows an interference picture of the temperature field formed by natural convection inside and outside a heated, hollow cylinder. The displacement of the fringes can be interpreted, by calculation, in terms of air temperature. Thus the locus of the points of equal fringe shift will be an isothermal line. If, for the initial, undisturbed condition, the interferometer is adjusted for a single or infinite width fringe, each fringe in the resulting picture when the cylinder is heated represents an isothermal line itself as shown in Fig. 26. The change in temperature from one fringe to the next is approximately 2 C.

The outstanding advantages of the interferometric method of analysis are the extreme sensitivity which can be obtained and the relative ease of obtaining quantitative information. Together the shadowgraph, schlieren and interferometric techniques are playing an important part as a powerful tool in the study of high-speed, aerodynamic phenomena.

The author wishes to take this opportunity to express his sincere gratitude to Miss Leonore McAlonen and Mr. Frederick Thurston for their assistance in preparing the following bibliography. While a few of the earlier works in the fields listed are included in the bibliography, most of the literature referred to has been published in more recent times. Where an article refers to two or more of the three basic types of optical systems described or where an article describes a different type of system, such an article is listed under the heading of "General." The bibliography is by no means complete, and there are excellent references which could be added, many of which corresponding articles have a security classification. However, it is hoped that this bibliography as it is will be of valuable help to the many workers pioneering in this field.

BIBLIOGRAPHY

Schlieren Application

1. Allen, H. S., "The photography of sound waves and other disturbances," *Proc. Roy. Phil. Soc. (Glasgow), 33:* 71, 1902.
2. Barnes, G. M., "Supersonic wind tunnel laboratory at Aberdeen Proving Grounds," *Mech. Eng., 67:* 827, 1945.
3. Boelter, L. M. and Cherry, V. H., "Measurement of heat transfer by free convection from cylindrical bodies by schlieren method," *Heating, Piping and Air Conditioning, 10:* 671, 1938.
4. Bogdonoff, S. M., "NACA cascade data for the blade design of high performance axial-flow compressors," *J. Aeronaut. Sci., 15:* 89, 1948.
5. Busemann, Adolf, "The drag problem at high supersonic speeds," *J. Aeronaut. Sci., 16:* 337, 1949.
6. Cranz, C. and Bames, E., "High-frequency schlieren cinematography and its use for investigating explosions and other rapidly occurring phenomena," *Z. Anal. Chem., 36:* 76, 1923.
7. Dhawan, S. and Roshko, A., "A flexible nozzle for a small supersonic wind tunnel," *J. Aeronaut. Sci., 18:* 253, 1951.
8. Feng, K. I., "Schlieren observation in the DVL high speed wind tunnel," *ATSC Rep.*, Apr. 1946.
9. Garside, Hall and Townend, "Flow states in emergent gas streams," *Nature, 152:* 748, 1943.
10. Gawthrop, D. B., "Application of the Schlieren method of photography," *Rev. Sci. Instr., 2:* 522, 1931.
11. Gawthrop, D. B., "Propagation tests and the photography of the disturbance sent out by the explosion of commercial electric detonators," *J. Franklin Inst., 214:* 647, 1932.
12. Gothert, B., "High-speed measure-

ments on symmetrical bodies," *DVL Institut fur Aerodynamik*, July 1944.
13. Hertzberg, A. and Kantrowitz, A., "Studies with an aerodynamically instrumented shock tube," *J. Appl. Phys., 21:* 874, 1950.
14. Hertzberg A., "A shock tube method of generating hypersonic flow," *J. Aeronaut. Sci., 18:* 803, 1951.
15. "High speed motion picture photography," *Jour. SMPE, 53:* 440, 1949.
16. Humphrey, R. H. and Jane, R. S., "The observation of cataphoresis in colorless solutions," *Trans. Faraday Soc., 22:* 420, 1926.
17. Johnston, R. C., "Basic research in gas flow," *Tech. Eng. News:* 330, June 1948.
18. Klug, H., "Experimentelle Untersuchungen zur Schneidentonbildung," *Ann. d. Physik, 11:* 53, 1931.
19. Liepmann, H. W., "The interaction between boundary layer and shock waves in transonic flow," *J. Aeronaut. Sci., 13:* 623, 1946.
20. Liepmann, H. W. and Ashkenas, H. I., "Shock wave oscillations in wind tunnels," *J. Aeronaut. Sci., 14:* 295, 1947.
21. MacGregor, C. W., "The formation of localized slip layers in metals," *Metals and Alloys, 4:* 19, 1933.
22. Nadai, A., "Phenomenon of slip in plastic material," *Proc. Am. Soc. Test. Mat., 31:* 11–46, 1931.
23. Osterstrom, G. E., "Knocking combustion observed in a spark ignition engine with simultaneous direct and schlieren high-speed motion pictures and pressure records," *NACA U3835*, June 1948.
24. Payman, W., "The detonation wave in gaseous mixtures and the pre-detonation period," *Proc. Roy. Soc., A120:* 90, 1928.
25. Payman, W. and Robinson, H., "The pressure wave sent out by an explosive, Part I," *Safety in Mines Research Board Paper, No. 18*, 1926.
26. Payman, W. and Shepherd, W. C., "The pressure wave sent out by an explosive, Part II," *Safety in Mines Research Board Paper, No. 29*, 1926.
27. Payman, W. and Shepherd, W. C., "The disturbance produced by bursting diaphragms with compressed air," *Proc. Roy. Soc., A186:* 293, 1946.
28. Payman, W. and Titman, "The initiation of detonation in mixtures of ethylene and oxygen and of carbon monoxide and oxygen," *Proc. Roy. Soc., A152:* 418, 1935.
29. Payman, W. and Woodhead, D. B., "The wave speed camera and its application to the photography of bullets in flight," *Proc. Roy. Soc., 132:* 200–213 1931.
30. Pearce, R. B., "Supersonic tunnel for missiles," *Aviation Week, 49:* 22, Aug. 23, 1948.
31. Philpot, J. St. L., "Direct photography of ultracentrifuge sedimentation curves," *Nature, 141:* 283, 1938.
32. Prandtl, L., "Neue Untersuchungen über die strömende Bewegung der Gase und Dämpfe," *Physik. Z., 8:* 23, 1907.
33. Rothrock, A. M. and Spencer, R. C., *National Advisory Committee of Aeronautics 24th Annual Report*, 213, 1938.
34. Schrott, Carl, "Schlieren cinematography," *Die Kinotechnik, 12:* 40, 1930.
35. Shepherd, W. C., "The ignition of fire damp by explosives; a study of the process by schlieren methods," *Bur. Mines Bull.*, No. 354, 1932.
36. Stack, John, "The compressibility burble," *NACA TN543*, Oct. 1935.
37. Stack, John, "Compressible flows in aeronautics," *J. Aeronaut. Sci., 12:* 127, 1945.
38. "Supersonic wind tunnel," *Automotive Industries*, July 15, 1947.
39. Tawil, E. P., "Ultrasonic standing waves made visible in a gas by schlieren method," *Comptes Rendus, 191:* 92, 1930.
40. Tawil, E. P., "Observation methods for non-stationary sound waves," *Comptes Rendus, 191:* 998, 1930.
41. Tiselius, A., "A new apparatus for the electrophoretic analysis of colloidal mixtures," *Trans. Faraday Soc., 33:* 524, 1937.
42. Tiselius, A., "Schlieren method used to observe electrophoresis," *Trans. Faraday Soc., 33:* 524, 1937.
43. Tiselius, A., Pedersen and Eriksson-Quensel, "Observation of ultracentrifugal sedimentation by Toepler schlieren method," *Nature, 139:* 546, 1937.
44. Toepler, A., "Observations of the

singing flame by the schlieren apparatus," *Ann. d. Physik und Chemie., 128:* 126, 1866.

45. Toepler, A., "Optical studies by the schlieren method of observation," *Ann. d. Physik und Chemie., 131:* 33, 1867.
46. Toepler, M., "Neue einfache Versuchsanordnung zur bequemen subjektiven Sichtbarmachung von Funkenschallwellen nach der Schlierenmethode," *Ann. d. Physik, 27:* 1043, 1908.
47. Towend, H. C., "Statistical measurements of turbulence in the flow of air through a pipe," *Proc. Roy. Soc., A115:* 1934.
48. Townend, H. C., "A method of air flow cinematography capable of quantitative analysis," *J. Aeronaut. Sci., 3:* 343, 1936.
49. Townend, H. C., "Visual and photographic methods of studying boundary layer flow," *Aeronaut. Res. Comm. Great Brit. R & M,* #1803, 1937.
50. Turner, E. B., "Supersonic wind tunnel schlieren system," *Air Tech. Intelligence,* 35056.
51. Wood, R. W., "Photography of sound waves and the kinematographic demonstration of the evolutions of reflected wave fronts," *Phil. Mag., 50:* 148, 1900.
52. Wood, R. W., "On the propagation of cusped waves and their relation to the primary and secondary focal lines," *Phil. Mag., 52:* 589, 1901.

Schlieren Equipment

53. Bailey, D. Z., "Design and operation of schlieren system," *Gas Turbine Laboratory, M.I.T.,* unpublished report.
54. Barnes, N. F. and Bellinger, S. L., "Analyzing airflow," *G. E. Rev.,* Dec. 1944.
55. Barry, F. W. and Edelman, G. M., "An improved schlieren apparatus," *J. Aeronaut. Sci., 15:* 364, 1948.
56. Bradfield, W. S. and Fish, W. Y., "A high-speed schlieren technique for investigation of aerodynamic transients," *J. Aeronaut. Sci., 19:* 418, 1952.
57. Burton, Ralph A., "A modified schlieren apparatus for large areas of field," *J. Opt. Soc. Am., 39:* 907, 1949.
58. Burton, Ralph A., "Notes on the multiple source schlieren system," *J. Opt. Soc. Am., 41:* 858, 1951.
59. Fish, R. W. and Parnham, K., "Focussing schlieren systems," *Air Tech. Intelligence,* 101828, 1950.
60. Hartmann, Julius, "The acoustic air-jet generator," *Ingeniorvidenskabelige Skrifter* (Acad. Tech. Sci., Copenhagen), no. 4, 1939.
61. Herrington, R., "Design and construction of schlieren photography equipment," Rensselaer Polytechnic Institute, 1947.
62. Hett, J. H., "High speed stereoscopic schlieren system," *Jour. SMPTE, 56:* 214, 1951.
63. Kantrowitz, Arthur and Trimpi, R. L., "A sharp-focusing schlieren system," *J. Aeronaut. Sci., 17:* 311, 1950.
64. Liepmann, H. W., "The 2″ x 20″ transonic wind tunnel," *Final Report for Supplement Agreement,* No. 1 (S-4843) to Contract No. W 33-038 with A.T.S.C., Wright Field, 1945.
65. Mortensen, T. A., "An improved schlieren apparatus employing multiple slit-gratings," *Rev. Sci. Instr., 21:* 3, 1950.
66. Prescott, R. and Gayhart, E. L., "A method of correction of astigmatism in schlieren systems," *J. Aeronaut. Sci., 18:* 69, 1951.
67. Townend, H. C., "Improvements in the schlieren method of photography," *J. Sci. Instr., 11:* 184, 1934.

Schlieren Theory

68. Gayhart, E. L. and Prescott, R., "Interference phenomenon in the schlieren system," *J. Opt. Soc. Am., 39:* 546, 1949.
69. Lamla, E., "Uber den Strahlengang bei Schlierenaufnahmen von einfachen ebenen Stosswellen," *Inst. f r Gasdynamik,* Oct. 1944.
70. *Report on the Second Conference of Fluid Dynamics* at Princeton, 1946, published by Navy Department, Bureau of Ordnance.
71. Rutkowski, J., "The schlieren method in flow observation of rarefied gases," *Air Tech. Intelligence,* 32955.
72. Schardin, H., "Das Toeplersche

Schlierenverfahren," *V.D.I. Forschungsheft* 367, Berlin 1934.
73. Schardin, H., "Toepler's schlieren method—basic principles for its use and quantitative evaluation," (translation of original paper) *Air Tech. Intelligence*, 22472.
74. Sevault, A., "Phenomenon of electric in supersonic nozzle," *Comptes Rendus* 225, #17, Oct. 27, 1947.
75. Shafer, H. J., "A physical optic analysis of the schlieren method," *Phys. Rev., 75:* 1313, 1949.
76. Straubel, R., "Dioptrik in Medien mit kontinuierlich variablem Brechungsindex," *Handbuch d. Physik, 6:* 485, 1906.
77. Taylor, H. G. and Waldran, J. M., "Improvements in the schlieren method," *J. Sci. Instr., 10:* 378, 1933.
78. Toepler, A., *Observation on a New Optical Beam*, Bonn, 1864.
79. Williams, T. W. and Benson, J. M., "Preliminary investigation of the use of afterglow for visualizing low-density compressibility flows," *NACA U3715*, Feb. 1949.
80. Wood, R. W., "Photography of sound waves by the schlieren method," *Phil. Mag., 48:* 218, 1899; *50:* 148, 1900.

Shadowgraph Photography

81. Barg, J., "Anyone can make photograms," *Am. Phot., 44:* 49, 1950.
82. Bull, G. V., "Investigation into the operating cycle of two-dimensional supersonic wind tunnel," *J. Aeronaut. Sci., 19:* 609, 1952.
83. Charters, A. C. and Thomas, R. N., "Spark photography of $^{9}/_{16}$" diameter spheres," *J. Aeronaut. Sci., 12:* 468, 1945.
84. Clark, J. C., "Spark photographic techniques at the applied physics lab. at Tokyo Imperial University," Dec. 1945.
85. Cooper, G. E. and Rothert, G. A., Jr., "Visual observations of the shock wave," *NACA RM* No. A8C25, 1948.
86. Cranz, C., *Lehrbuch der Ballistik, 2,* 193; *3,* 271; Julius Springer, Berlin, 1926.
87. Cranz, C. and Glatzel, B., "Die Ausströmung von Gasen bei hohen Anfangsdrucken. I. Teil," *Ann. d. Physik, 43:* 1186, 1914.
88. Cranz, C. and Koch, R., "Über die explosionsartige Wirkung moderner Infanteriegeschosse," *Ann. d. Physik, 3:* 247, 1900.
89. Emden, R., "Über die Ausströmungserscheinungen permanenter Gase," *Ann. d. Physik, 69:* 264, 1899.
90. von Kármán, Theodore, "Supersonic aerodynamics—principles and applications," *J. Aeronaut. Sci., 14:* 373, 1947.
91. Keenan, P. C., "Shadowgraph method of determining the strength of a shock wave," *Phys. Rev., 69:* 677 1946.
92. Keenan, P. C. and Polachek, H., "Measurement of densities in Shock waves by the shadowgraph method," *NAVORD Rep.* 86-46.
93. Killing, V., "New techniques in photograms," *Am. Phot., 46:* 13, 1952.
94. Lafay, A., "Sur l'utilisation du procédé d'exploration à l'acetylène pour la mesure de la vitesse du vent et l'étude du champ aerodynamique," *Comptes Rendus, 152:* 694, 1911.
95. McMillen, J. H. and Harvey, E. N., "A spark shadowgraph study of body waves in water," *J. Appl. Phys., 17:* 541, 1946.
96. McMillen, J. H., Kramer, R. L. and Allmand, D. E., "Shadowgrams of spherical missiles entering water at supersonic speeds," *J. Appl. Phys., 21:* 1341, 1950.
97. Marlow, D. G. and Nisewanger, C. R., "Development of the spark shadowgraphs," *Air Tech. Intelligence*, 39131.
98. Scheyer, B., "Special effects with photograms," *Am. Phot., 43:* 506, 1949.
99. Schmidt, E., "Wärme und Kältetechnische Forschungen," *Z.V.D.I., 74:* 1487, 1930.
100. Stevens, V. I., "Hypersonic research facilities at Ames Aeronaut. Laboratory," *J. Appl. Phys., 21:* 1150, 1950.
101. Tanakadate, A., "Photographic study of air current produced by the movement of a screw propeller," *Comptes Rendus, 151:* 211, 1910.
102. Taylor, G. I. and Maccoll, J. W.,

"The air pressure on a cone moving at high speeds," *Proc. Roy. Soc., A139:* 298, 1933.

103. Townend, H. C., "Hot wire and spark shadowgraphs of the airflow through an air stream," *Phil. Mag., 14:* 700, 1932.
104. Wachsmuth, R., "Labialpfeifen und Lamellentöne," *Ann. d. Physik, 14:* 469, 1904.

Interferometric Application

105. Bennett, F. D., Carter, W. C. and Bergdolt, V. E., "Interferometric analysis of airflow about projectiles in free flight," *J. Appl. Phys., 23:* 453, 1952.
106. Berl, E., "Die Anwendung der Interferometrie in Wissenschaft und Technik," *Fortschritte der Chemie, Physik und Phys. Chemie., 19:* 7, 1928.
107. Bershader, D., "An interferometric study of supersonic channel flow," *Rev. Sci. Instr., 20:* 260, 1949.
108. Blue, R. E., "Interferometer corrections and measurements of laminar boundary layer in supersonic stream," *NACA TN* 2110, 1950.
109. Eckert, E. R. and Soehngen, E. E., "Studies on heat transfer in laminar free convection with the Zehnder-Mach interferometer," *USAAF TR,* No. 5747, Dec. 1948.
110. Gooderum, P. B., Wood, G. P. and Brevoort, M. J., "Investigation with an interferometer of the turbulent mixing of a free supersonic jet," *NACA TN* 1857, Apr. 1949.
111. Groth, E., "Evaluation of density fields around airfoils in wind tunnels by means of optical interference," *AVA Gottingen,* Film 211, May 1946.
112. Groth, E., "Evaluation of interferometer measurements on aerofoil in the 250 x 250 mm. high-speed tunnel," *Air Tech. Intelligence, 33:* 769.
113. Groth, E., "The evaluation of density field at high subsonic velocities by means of optical interference methods," *Air Tech. Intelligence,* 9888 Dec. 1943.
114. Groth, E., "Evaluation of density fields at high subsonic velocities by means of optical interference measurements," *N.A.A. Report N.A.,* 8783, Nov. 26, 1945.
115. Groth, E., "Measurement of flow around the airfoil by means of a Mach-Zehnder interferometer," Joint Intelligence Objectives Agency, Washington, BIGS-94, ADG 1011, Aug. 21, 1946.
116. Groth, E., "Sensitivity and accuracy of the interference method applied to pressure measurements in wind tunnels," *Air Tech. Intelligence,* 36783, *ADG* 1042.
117. Hansen, G., "Uber die Ausrichtung der Spiegel bei einem Interferometer nach Zehnder-Mach," *Z. Instrumentenk, 60:* 325, 1940.
118. Holden, J., "Shape of reflected interference fringes from interferometers coated with thin metal films," *J. Opt. Soc. Am., 41:* 504, 1951.
119. Hottenroth, "Über Einige Erfahrungen am Mach-Zehnderschen Interferometer," *Forschungs bericht* Nr. 1924, LFA, Braunschweig, Dec. 31, 1943 (Translated Air Doc. Div. T-2, Ame. Wright Field) *Air Tech. Intelligence,* 26635.
120. Hutton, S. P., "The use of interferometers in aerodynamics," TN No. Aero. 1808, *Royal Aircraft Establishment Report.*
121. Kennard, R. B., *Temperature Distribution and Heat Flux in Air by Interferometry; Temperature, Its Measurement and Control,* Reinhold Publishing Corporation, New York, 1941.
122. Ladenburg, R., "Interferometric analysis of supersonic jets," *NAVORD Report* 74-46.
123. Ladenburg, R., Panofsky, Van Voorhis, C. C. and Winckler, J., "Study of shock waves by interferometry," *NDRC Report* No. A 332 OSRD No. 5204.
124. Ladenburg, R., Van Voorhis, C. C. and Winckler, J., "Interferometric study of supersonic phenomena," *NAVORD Report* 69-46; *NAVORD Report* 93-46; *NAVORD Report* 7-47.
125. Laue, M., "Interference phenomena with plane parallel plates," *Ann. d. Physik, 13:* 163, 1903.
126. Laurence, J. C., "Interference method for obtaining the potential flow past an arbitrary cascade of airfoils," *NACA TN* 1252, 1947.
127. Liepmann, H. W. and Bryson, A. E.,

Jr., "Transonic flow past wedge sections," *J. Aeronaut. Sci. 17:* 745, 1950.
128. Mach, E., *Ann. d. Physik., 159:* 330, 1876.
129. Mach, E., "The interference of spherical waves," *Ann. d. Physik, 41:* 140, 1890.
130. Mach, E. and Gruss, *Wien. Ber., 78:* 467, 1879.
131. Mach, E. et alia, Various Papers, *Sitzungsber. d. Kais. Akad. d. Wissenschaften in Wien, 95:* 764, 1887; *98:* 41, 1303, 1889.
132. Mach, E. and Weltrubsky, J., "Über die Formen der Funkenwelle," *Wien. Ber., 78:* 551, 1878.
133. Matta, K. and Richardson, E. G., "Hot wire ultrasonic interferometer and its application to vapors," *J. Acoust. Soc. Am., 23:* 58, 1951.
134. Olsen, H. L., "An interferometric method of gas analysis," *Univ. of Wisconsin, CM*-514 NORD 9938, Nov. 1948.
135. Ostwatitoch, K., "The measurement of density in an airstream by means of the double-slit interferometer," *Air Tech. Intelligence*, 18 473.
136. Pack, D. C., "Investigation of the flow past finite wedges of 20 degree and 40 degree apex angle at subsonic and supersonic speeds using a Mach-Zehnder interferometer," *British R. & M.*, No. 2321, 1949.
137. Saunders, J. B., "An apparatus for photographing interference phenomena," *J. Research Nat. Bur. Standards, 35:* 157, 1945.
138. Schulz, L. G., "Interferometric method for accurate thickness measurements of thin evaporated films," *J. Opt. Soc. Am., 40:* 690, 1950.
139. Tolansky, S., *Multiple-Beam Interferometry of Surfaces and Films*, Clarendon Press, Oxford, 1948.
140. Tolansky, S., "New contributions to interferometry with applications to crystal studies," *J. Sci. Instr., 22:* 161, 1945.
141. Twyman, F., "Interferometers for the experimental study of optical systems from the point of view of the wave theory," *Phil. Mag., 35:* 49, 1918.
142. West, G. D., "An interferometer for sound waves," *J. Sci. Instr., 6:* 254, 1929.
143. Williams, W. E., *Applications of Interferometry*, John Wiley and Sons, New York, 1950.
144. Winckler, J., "The Mach Interferometer applied to studying an axially symmetric supersonic air jet," *Rev. Sci. Instr., 19:* 307, 1948.
145. Work, R. N., "A photoelectric recording interferometer for measurement of dimensional changes," *J. Research Nat. Bur. Standards, 47:* 80, 1951.
146. Zobel, T. W., "Flow Measurements by Light Interference," *Air Tech. Intelligence*, 26 165.
147. Von Vietinghoff-Scheel, K., "Laboratory report on the investigation of flow around two turbine blade profiles using the interferometer method," *NACA TM*, 1171, 1947.

Interferometric Equipment

148. Ashkenas, Harry I. and Bryson, Arthur E., "Design and performance of a simple interferometer for wind tunnel measurements," *J. Aeronaut. Sci., 18:* 82, 1951.
149. Bergdolt, V. E., "A new interferometer with a large working field," *Ballistics Res. Lab. Rep.* 692, 1949; also *Air Tech. Intelligence*, 61 168.
150. Candler, C., *Modern Interferometers*, Hilger & Watts Ltd., London, 1951, available from Jarrell-Ash Co., Boston.
151. DeFrate, L. A., Barry, F. W. and Bailey, D. Z., "A portable Mach-Zehnder interferometer," *Project Meteor Report No. 51*, Feb., 1950.
152. Eckert, E. R., Drake, R. M., Jr. and Soehngen, E. E., "Manufacture of a Zehnder-Mach interferometer," *USAAF TR* No. 5721, Aug., 1948.
153. Hansen, G., "Über ein Interferometer nach Zehnder-Mach," *Z. Tech. Physik., 12:* 436, 1931.
154. Kahl, G. D. and Bennett, F. D., "Experimental verification of source size theory for the Mach-Zehnder interferometer," *J. Applied Phys., 23:* 763, 1952.
155. Keating, T. J., "The Zehnder-Mach Interferometer," *Plane Facts*, 20-21, Oct. 1948.
156. Lamla, E., "Calibration of the Mach-Zehnder Interferometer," *Air Tech. Intelligence*, 38908.

157. Mach, L., "Über ein Interferenzrefraktometer," *Wien. Ber., 101:* 5, 1892; *102:* 1035, 1893.
158. Mach, L., "Über Einige Verbesserungen an Interferenzapparaten," *Wien. Ber., 107:* 851, 1898.
159. Peck, E. R., "A New Principle in Interferometer Design," *J. Opt. Soc. Am., 38:* 66, 1948.
160. Price, E. W., "Initial adjustment of the Mach-Zehnder interferometer," *Rev. Sci. Instr., 23:* 162, 1952.
161. Simmons, L. F. and Salter, C., "Interferometer for recording turbulent flow," *Aeronaut. Res. Comm. Great Brit. Rep.* 1454, 1932.
162. Waran, H. P., "New form of interferometer," *Proc. Roy. Soc. A 100:* 419, 1922.
163. Winckler, J., "A mechanical evaluation method for interferometer photographs," *Air Tech. Intelligence*, 1964.
164. Zehnder, "Ein Neuer Interferenzrefraktor," *Z. Instrumentenk, 11:* 275, 1891.
165. Zobel, T. W., "The development and construction of an interferometer for optical measurements of density fields," *NACA TN* No. 1184, also in *Air Tech. Intelligence* 22550.
166. Zobel, T. W., "Optical corrections for interference by a controllable deformation of the reflecting surfaces," *Air Tech. Intelligence* 31 053.

Interferometric Theory

167. Bennett, F. D., "Optimum source size for the Mach-Zehnder interferometer," *J. Appl. Phys., 22:* 184, 1951
168. Bennett, F. D. and Kahl, G. D., *Theory of Mach-Zehnder Interferometer* (to be published).
169. Clippinger, R. F., "Comparison between the Jamin-Mach interferometer and the Williams interferometer as applied to the study of airflow around a supersonic projectile of revolution," *Ballistics Research Lab. Report 567*, Aberdeen, Sept. 21, 1945.
170. Kennard, R. B., "An optical method for measuring temperature distribution and convective heat transfer," *J. Research Nat. Bur. Standards., 8:* 787, 1932.
171. Kinder, W., "Theorie des Mach-Zehnder Interferometers und Beschreibung eines Gerätes mit Einspiegeleinstellung," *Optik, 1:* 413, 1946.
172. Lamla, E., "Concerning the light path in a Mach-Zehnder interferometer," *Jahrbuch 1941 der Deutschen Luftfahrtforschung*, 727, Royal Aircraft Establishment Translation No. 80.
173. Peck, E. R., "Theory of the corner-cube interferometer," *J. Opt. Soc. Am., 38:* 1015, 1948.
174. Schardin, H., "Theorie und Anwendung des Mach-Zehnderschen Interferenz-Refraktometers," *J. Instrumentenk, 53:* 396, 424, 1933.
175. Weyl, F. J., "Numerical aspects o. quantitative interferometry," *Phys Rev., 69:* 677, 1946.
176. Winckler, E. H., "Analytical studies of the Mach-Zehnder interferometer," *N.O.L. Report*, 1077, Dec. 1949.

General

177. Adams, G. K., "A repetitive spark source for shadow and schlieren photography," *J. Sci. Instr., 28:* 379 1951.
178. Barnes, N. F. and Bellinger, S. L., "Schlieren and shadowgraph equipment for air flow analysis," *J. Opt. Soc. Am., 35:* 497, 1945.
179. Barry, F. W., Shapiro, A. H. and Neumann, E. P., "The interaction of shock waves with boundary layers on a flat surface," *J. Aeronaut. Sci., 18:* 229, 1951.
180. Beardsley, E. G., "The NACA photographic apparatus for studying fuel sprays from oil engine injection valves and test results from several researchers," *NACA Tech. Rep.*, 274, 1927.
181. Bleakney, W., Weimer, D. K. and Fletcher, C. H., "Shock tube; a facility for investigation in fluid mechanics research," *Rev. Sci. Instr., 20:* 807, 1949.
182. Brenholtz, G. E., "An investigation of methods of visual flow," *Air Tech. Intelligence*, 89619, 1950.
183. Brown, G. B., "On sensitive flames," *Phil. Mag., 13:* 161, 1932.
184. Brown, G. Burniston, "On vortex motion in gaseous jets and the origin

of their sensitivity to sound," *Proc. Phys. Soc., 47:* 703, 1935.

185. Buchele, D. R. and Day, P. B., "Interferometer with large working field utilizing schlieren optics," *NACA RM*, E50 I27, 1951.
186. Dernback, A. F., "Interference method of studying airflow as used at the LFA Research Center," May 1945.
187. Edgerton, H. E., "Double-flash microsecond silhouette photography," to be published in *Rev. Sci. Instr.*
188. Egerton and Gates, "On detonation of gaseous mixtures of acetylene and of pentane," *Proc. Roy. Soc., A114:* 137, 152, 1927.
189. Fage, A., "On the static pressure in fully developed turbulent flow," *Proc. Roy. Soc., 155:* 576, 1936.
190. Fage, A. and Townend, H. C., "An examination of turbulent flow with an ultramicroscope," *Proc. Roy. Soc., A135:* 656, 1932.
191. Fayolle, P. and Naslin, P., "Photographie instantanée et cinematographie ultra-rapide," *Editions de la Revue d'Optique*, Paris, 1950.
192. Ferri, Antonio, *Elements of Aerodynamics of Supersonic Flows*, Macmillan, New York, 1949.
193. Foucault, *Annales de l'Observatoire Imp. de Paris, 5:* 197, 1859.
194. Garby, L. C. and Nelson, W. C., "University of Michigan 8 x 13 inch intermittent-flow supersonic wind tunnel and appendix," *Air Tech. Intelligence*, 80958, June 1950.
195. Gawthrop, D. B., Shepherd, W. C. and St. Perrolt, G., "The photography of waves and vortices produced by the discharge of an explosive," *J. Franklin Inst., 211:* 67, 1931.
196. Jacobs, E. N., "Methods employed in America for experimental investigation of aerodynamic phenomena at high speeds," *NACA Misc. Paper #42*, Mar. 1936.
197. Jones, E., "Photographic study of detonation in solid explosives," *Proc. Roy. Soc., 120:* 603, 1928.
198. Kantrowitz, A. and Donaldson, C., "Preliminary investigation of supersonic diffusers," *NACA ACR* L5D20, 1945.
199. Ladenburg, R., Winckler, J. and Van Voorhis, C. C., "Interferometric studies of faster than sound phenomena," *Phys. Rev., 73:* 1359, 1948 and *Phys. Rev., 76:* 662, 1949.
200. Liepmann, H. W. and Puckett, A. E., *Introduction to Aerodynamics of Compressible Fluids*, John Wiley and Sons, New York, 1947.
201. MacColl, J., "The conical shock wave formed by a cone moving at high speeds," *Proc. Roy. Soc., 159:* 459, 1937.
202. Moore, A. D., "Further development of fluid mappers," *Elec. Eng., 70:* 396, 1951.
203. *National Physical Laboratory Annual Report for 1932.*
204. "Kinematography of air flow," *National Physical Laboratory Annual Report for 1933.*
205. Nelson, R. A., "Free convection of heat in liquids," *Phys. Rev., 23:* 94, 1924.
206. Nicholson, H. M. and Field, J. P., "Some experimental techniques for the investigation of the mechanism of flame stabilization in the wakes of bluff bodies," *NOrd*, 7386, Johns Hopkins University, Dec. 1948.
207. Pugh, E. M., Heine-Geldern, R., Foner, S. and Mutschler, E. C., "Glass cracking caused by high photography," *J. Appl. Phys., 23:* 48, 1952.
208. Smith, L. G., "Photographic investigation of the reflection of plane shocks in air," *Phys. Rev., 69:* 678, 1946.
209. Strong, J., *Procedures in Experimental Physics*, Prentice-Hall, New York, 1938.
210. *Symposium on Wind Tunnel Optics, Air Tech. Intelligence*, 82 325.
211. Taylor, G. I. and MacColl, J., "Air pressure on a cone moving at high speeds," *Proc. Roy. Soc., 139:* 278, 298, 1933.
212. Taylor, M. K., "A balsa-dust technique for air-flow visualization and its application to flow through model helicopter rotors in stator thrust," *NACA TN* 2220, 1950.
213. Tietjens, O., Wien, W. and Harms, J. *Handbuch der Experimental Physik I:* 695, Leipzig, 1931.
214. Tilton, L. W., "Optical glass of interferometer and schlieren quality for wind tunnel optics," *J. Research Nat. Bur. Standards, 42:* 279, 1949.

215. Tremblot, R., "Sur l'étude des courants gazeaux au moyen des interferences," *Comptes Rendus, 192:* 480, 1931.
216. Tremblot, R., "Sur l'application des interferences à quelques problèmes d'écoulement à grandes vitesses," *Comptes Rendus, 193:* 418, 1931.
217. Von der Heyden, E., Jr., "The design of schlieren and shadowgraph apparatus for the proposed wind tunnel at R.P.I.," *Air Tech. Intelligence,* 66990, June 1949.
218. Weyl, F. J., "Analytical methods in the optical examination of supersonic flow," *NAVORD Rep. 211-45,* Dec. 1945.
219. Williams, T. W. and Benson, J. M., "Preliminary investigation of the use of afterglow for visualizing low-density compressible flows," *NACA TN* 1900, 1949.

Conversion of 16mm Single-Head Continuous Printers for Simultaneous Printing of Picture and Sound on Single-System Negative

By VICTOR E. PATTERSON

The big rush for television news release prints from single-system negative prompted the design of this conversion unit. In news work every possible shortcut must be taken, without lowering the quality of the release prints. These converted printers cut the printing time in half; also, they save considerable raw stock, because in loop printing a splice may give way and create a synchronization problem in resplicing the negative, with the result that stock with sound printed but no picture usually has to be discarded. No loss occurs when picture and sound are printed simultaneously on these printers.

In NOVEMBER of 1951, McGeary-Smith Laboratories of Washington, D.C., requested a unit to attach to one of their Bell & Howell Model J printers to print single-system sound and picture at one time in order to speed up the printing of television news film. The unit described in this article was made and attached to one printer. It worked so efficiently and saved so much valuable time that a second printer was promptly converted.

These units make it possible for prints to be taken off the processing machines in 30 to 40 min after negative is received for timing and printing. Also, by using negative on a loop tree for continuous printing, one printer running at 90 fpm can keep a processing machine going at 80 fpm. This conversion may prove of interest and value to laboratories doing television news work.

Although it does not save time on double-system sound, the printer remains available for this work simply by turning off the lamp not needed at the time. In case of printer trouble this unit may be quickly removed and installed on another printer, as no drilling or tapping is done on the printer casting; instead existing screw holes are used. As a result of the design of the attachment the printer may be restored to its original design by merely removing the attachment and replacing the single-head printer parts.

Figure 1 shows the parts needed for this conversion, consisting essentially of a prism made of plexiglas or optical glass (the one used here is optical glass). The prism has a tongue cut on its face which extends into the printing aperture

A contribution submitted August 5, 1953, by Victor E. Patterson, Telex Films, 5805 44th Ave., Hyattsville, Md.

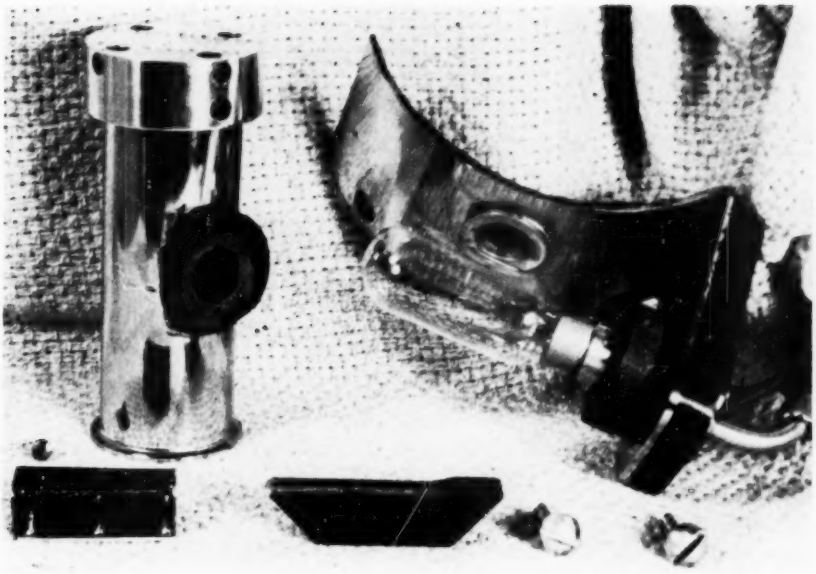

Fig. 1. Parts used in conversion.

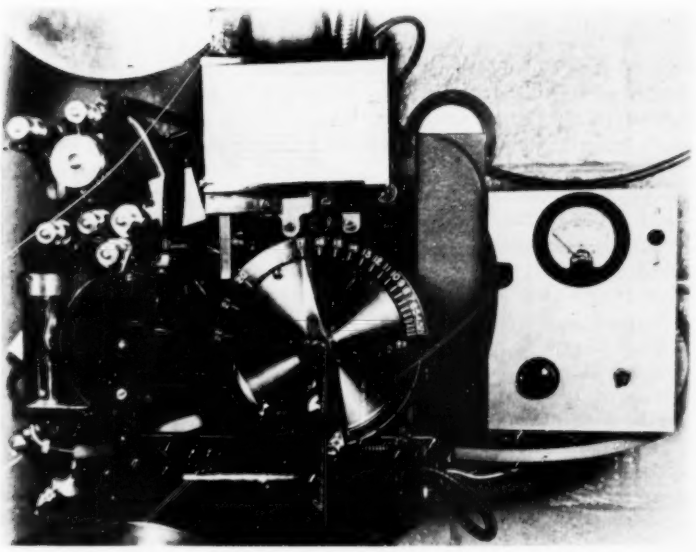

Fig. 2. Model J printer with unit attached to aperture housing. Electrical circuit box is fastened to printer fuse box.

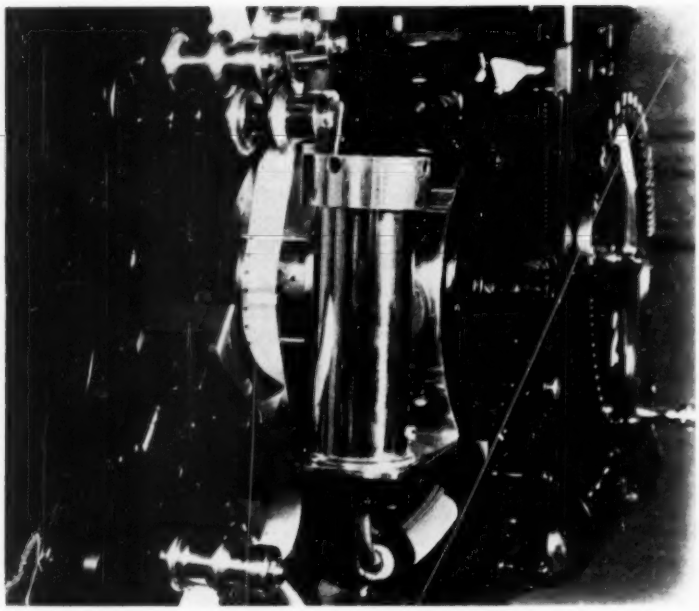

Fig. 3. Printer aperture with picture and sound lamps on. Air hose at bottom of lamp house is for cooling.

as the original slide did on the printer. With this design there is no need for a partition between the picture and sound which might cause shading of the track area.

A 50-w T-8 single-contact 120-v base lamp is used. The bracket for the lamp assembly is made from 14-gauge stainless steel formed to fit the printer housing and fastened on with two $\frac{1}{4}$-in. 20 screws. Formica is attached to this to hold the lamp base with an adjustment for moving the lamp up and down and around to center the filament. Also, a short length of stainless $\frac{1}{4}$-in. tubing is inserted in the base for a compressed-air hose for cooling. The lamp cover is a piece of tubing with a light-tight cap. One screw locks the cover to the lamp base to prevent accidental removal while printing. The little prism cover locks the prism in the aperture after it has been adjusted. The six 2-56 screws that held the slide in place are used to fasten cover and prism to the printer.

Figure 2 shows the unit installed on a printer. On the opposite side, attached to the fuse box, is a 7 × 9 in. radio chassis which holds a 0–150-v d-c meter, a 50-w 100-ohm variable resistor and a single-pole, single throw switch with a neon jewel light for Off and On of sound track lamp. The circuit is connected to the picture-lamp d-c power supply.

Figure 3 shows the printer aperture with a piece of raw stock in place with the picture and sound lamps on. At the bottom of picture air hose and lamp wires go to rear of printer. After printing tests were made, it was found that 86 *v* were correct for normal track exposure, which gives a long life to the lamp.

To install this unit, first remove the housing cover plates as for normal main-

tenance and cleaning. Then the aperture slide adjustment knob and eccentric cam are removed; also the slide and cover. These parts are left off the printer. After removing these parts there is exposed a $\frac{1}{2}$-in. hole where the adjustment knob was located. This is used for the light path from lamp to prism.

Next, two $\frac{1}{4}$-20 screws are removed along side of the printer gate. These are replaced with two round-head $\frac{1}{4}$-20 screws $\frac{1}{2}$ in. long to bolt the sound-lamp assembly to the housing. While doing this the filament is lined up with the center of the original hole that the adjustment knob was formerly in. The prism is placed in the aperture with its cover, which is left loose until the prism is adjusted for field and track placement. After the lamp is wired and the circuit connected to the power supply the final adjustment of the prism is made with picture and sound lamps on and a composite negative in the gate. Then the prism cover screws are tightened securely. In making this adjustment the lamp bracket may be moved slightly, as well as the lamp, to get the maximum light output. The housing cover plates are put back on and the printer is ready for an exposure test.

The prism is quite simple to adjust for track placement, and the field is good due to diffusion through the long prism. No condenser or reflector is needed, as the lamps burn far below their rated voltage (86 v for normal track on fine-grain release positive).

The electrical circuits for these units were made and wired to the printers by Arthur Rescher of McGeary-Smith Laboratories, where for more than two years they have been used with a great reduction of printing time and maintenance problems.

An Improved Carbon-Arc Light Source for Three-Dimensional and Wide-Screen Projection

By EDGAR GRETENER

Three-dimensional and wide-screen projection both require substantially more than the conventional amount of screen light. The super Ventarc has been designed to meet these requirements to such an extent that the screen lumens are only limited by the maximum density of radiant energy the film can take. If this value is set at 0.7 w/sq mm, the ultimate limit for a 35mm projection system will be approximately 50,000 lm, with no film shutter. This level of screen light has been attained at 150 amp.

Continuous Burning

The recommended operation time for three-dimensional projection is 60 min continuous burning of the arc. Mirror arcs of normal design can take positive carbons up to only 20 in. in length. The positive support or carbon-guiding mechanism requires a carbon stub of about 2 in., and so reduces the useful carbon length to 18 in. As the consumption rate shows some variations, a safety margin of 10% should be provided. This means a further reduction of the useful carbon length to about 16 in. Limited by this consumption rate, the most screen lumens a present-day reflector-type arc can produce with 80% screen distribution is 20,000, with an arc current of 115 amp and no film shutter.

Up to the maximum limit for smooth operation, the screen light a high-intensity arc can produce increases with the increasing consumption rate of the positive carbon, since the vapors produced by the evaporation of the carbon core constitute the light source. It thus becomes necessary for maximum light that any limitation on carbon consumption rate be removed. Such limitations can be overcome by an arc which is capable of continuous burning. In order to do this it becomes necessary to attach a new carbon to the burning one as soon as the latter is consumed to a minimum length determined by the carbon support. This problem of joining positives proved to be a very difficult one for a cinema arc, since no failure of the joining process can be tolerated with a continuous show. Furthermore, the quality of the joint has to be such that no flicker or color change of the projection light appears on the screen when the joint burns through the arc.

The process of joining positive carbons has been worked out by our firm in the past two years, with the kind assistance of the National Carbon Company. The

Presented on October 9, 1953, at the Society's Convention at New York by Hans Frey, Dr. Edgar Gretener, A. G., Ottenweg 25, Zürich, Switzerland, for Edgar Gretener.
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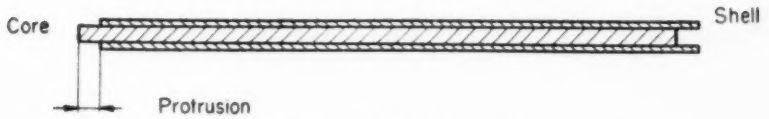


Fig. 1a. Positive carbons.

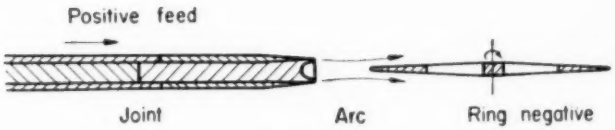


Figure 1b

results are now so satisfactory that this method is ready for practical use.

The nonrotating positive carbon of the Super Ventarc Lamp makes the joining problem much easier. From a practical point of view, the dimensional tolerances normally associated with large-scale production processes must be taken into consideration, so that a joining method requiring a very high precision of the parts to be joined would be of little practical interest. The positive carbons for continuous operation are designed as shown in Fig. 1a, so that the core protrudes at one end, with a complementary hole formed at the other. A magazine holding positive carbons is provided in the lamphouse. As soon as the length of the burning carbon reaches a certain value, a contact is operated which causes a new carbon to leave the magazine and be joined to the burning carbon, the hollow end of the new carbon sliding over the protruding core on the cold end of the burning one (Fig. 1b). The parts to be joined are impregnated by the manufacturer with a special cement. As the joint moves toward the positive head, it is heated by a simple electrical oven, which hardens the cement. The magazine can be designed to take any quantity of positive carbons, and it can be refilled while the arc is burning.

With the continuous feed for the positive carbons, an adequate system must also be provided for the negative electrode. To obtain maximum brilliance from the arc, the current density in front of the positive crater must be increased to the maximum extent possible, thus causing a high evaporation rate of the positive carbon. With a rod negative and an arc length of reasonable value, this would give rise to "mushroom" deposits on the tip of the negative, resulting in erratic burning. These difficulties are overcome by the use of a disk negative, mounted in a meridional plane of the illumination system. During operation of the arc, this negative disk is slowly rotated. All evaporation products condensing at the edge of the disk are thus transported outside the arc stream and oxidized in the open air. The disk consumes slowly at a rate dependent upon the arc current and other factors, and has a useful life of the order of five to ten hours burning time. The blown arc equipped with the continuous feed mechanism for the positives and combined with a suitably designed disk negative thus constitutes a source which can meet any requirement for cinema projection, within the limits imposed by the sensitivity of the film to the heat generated.

The Light Source

If the rate of evaporation of the core is high enough, the concentrated arc stream in front of the positive crater

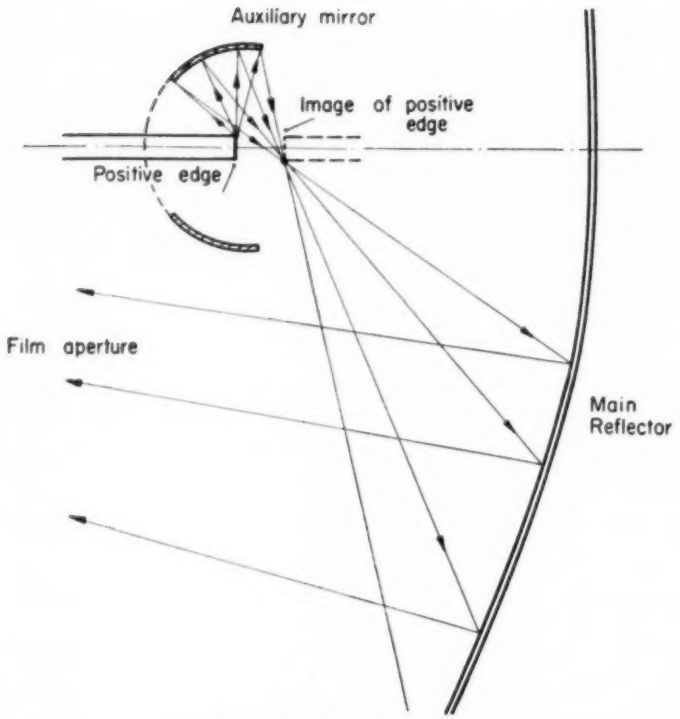


Fig. 2. Illumination system.

shows the same brightness as the crater itself. The absorption in the arc rises with increasing evaporation of the positive core until the crater edge is no longer visible through the arc. Under these conditions the arc stream replaces the positive crater as the light source. The brilliancy of this arc stream decreases with increasing distance from the crater. To get a cylindrical source of constant brilliancy along its axis, an auxiliary mirror is provided near the arc, as shown in Fig. 2. This auxiliary mirror picks up the back radiation of the arc stream and forms an inverse image of the arc in itself. Seen from the direction of the main mirror the arc stream seems to operate between two positive carbons (Fig. 2).

This light cylinder produces many more lumens than the crater itself, and in addition it offers much better conditions for the illumination system. Referring to Fig. 3a, a flat source produces a very sharp peak in the center of the film aperture if the collecting angle α of the mirror is increased to 90° in order to collect all the radiation of the flat source. This is due to the fact that the mirror-surface elements near the edge of the mirror see the source as a very narrow ellipse, with the small axis degenerating to zero for a 90° viewing angle. Because of this bad effect, the collecting angle of the mirror is normally limited to 70–75°.

In contrast with this, the cylindrical light source offers its very best qualities from a viewing angle of 90° to the carbon axis. This is illustrated in Fig. 3b.

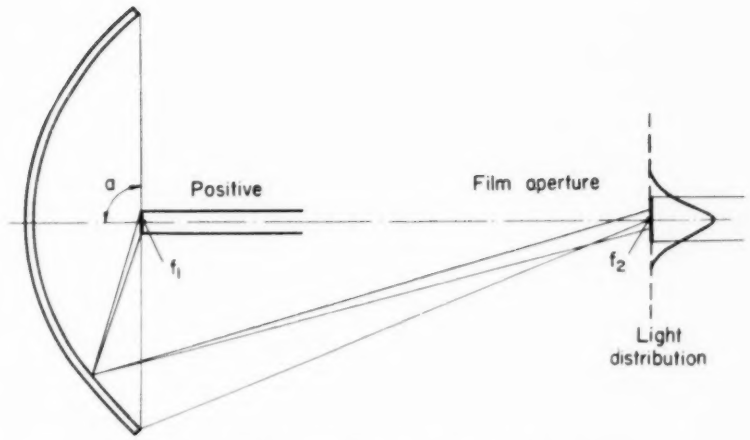


Fig. 3a. Elliptical reflector in focus $f_1 f_2$ flat source.

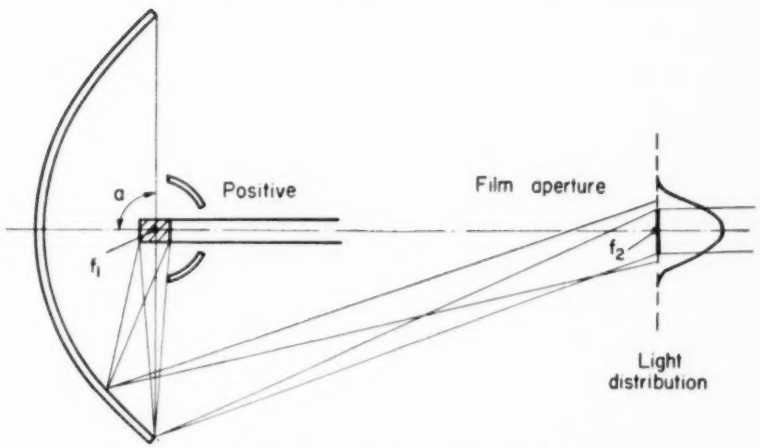


Fig. 3b. Elliptical reflector in focus $f_1 f_2$ cylindrical source with auxiliary mirror.

The illumination system of the Super Ventarc has therefore been designed to embrace the total solid angle around the source, the auxiliary mirror and the main mirror having each a collecting angle of about 90°.

The combination of the two mirrors not only picks up the total radiation from the cylindrical source, thus giving maximum efficiency for the illumination of the film aperture, but also prevents the lamp house from being heated by waste light from the arc.

Maximum Screen Illumination

The maximum possible light flux for a projection system is limited by the tolerable density of radiant energy in

the film aperture. This limit is not precisely established, but it is known to be in the neighborhood of 0.7 w/sq mm (measured with no film shutter) for normal projectors without forced-air cooling. This unit value holds for every part of the film area, so that a hot spot in the center of the aperture limits the total screen lumens long before the tolerable density of radiant energy is reached for the sides and corners of the picture. For this reason, uniform screen illumination is desirable. In any event, bad light distribution is particularly to be avoided in the projection of three-dimensional and wide-screen pictures.

For highest screen lumens, the highest possible ratio of lumens per watt has to be provided at the aperture. Without heat filters, a high-intensity arc gives about 115 aperture lm/aperture w, with no shutter. Cutting all invisible radiation, this goes up to 230 lm/w. Further cutting of the red and blue end of the visible spectrum raises this ratio to 300 lm/w, if the white is permitted to shift one threshold toward green. This is not noticeable with a projection system if this greenish white cannot be compared directly with a correct white; and a light loss of no more than 1.75% is involved if all radiation beyond the range between 430 and 650 mμ is eliminated.

The ideal radiation filter transmitting 430 to 650 mμ will be of the interference type, but this is not yet commercially available; any practical filter will produce some light losses and transmit some invisible radiation. Further, the transmission factor T of a good surface-treated lens can be set to 0.90. Recognizing these factors, it is always useful to set up the final target. The ultimate screen-lumen figure thus becomes:

$$L = A \cdot \delta \cdot \eta \cdot T$$

where A is the area of the aperture in sq mm,

δ is the maximum tolerable radiant energy at the aperture in w/sq mm,

η is the luminous efficiency of this energy in lm/w,

and T is the lens transmission.

Substituting the values:

A = 320 sq mm for 35 mm film,

δ = 0.7 w/sq mm,

η = 300 lm/w, and

T = 0.9, we get

$L = 320 \times 0.7 \times 300 \times 0.9 =$ 60,000 lm without the film shutter.

This value holds for an even light distribution over the screen. With an 80% side-to-center distribution, it is reduced to 50,000 lm.

Any light losses of the heat filter can be compensated by a slight increase of the arc current, and any transmission of invisible radiation can be suppressed by additional filter layers. Consequently the 50,000 lm will be available in the future if the cutoff at both ends of the visible spectrum can be made sharp enough and if projection-lens efficiency is 90%. This ultimate screen-lumen figure will grow proportionally if the heat tolerance of the film can be increased by forced-air cooling or the use of improved film material.

It must be pointed out that infrared transmitting mirrors are not suitable for very high-current arcs, as the support glass will be spoiled in a short time by deposits from the arc. The Super Ventarc uses a metallic mirror evaporated with aluminum and with a protective layer of silicon monoxide. This protecting layer is so thin that its heat resistance is quite negligible. If hot particles fall on the surface of this mirror, the high heat conductivity of the metal prevents local melting, so that the particles do not fuse with the mirror surface but fall harmlessly to the bottom of the lamphouse. Comparative tests with a very heavily loaded positive crater showed the striking superiority

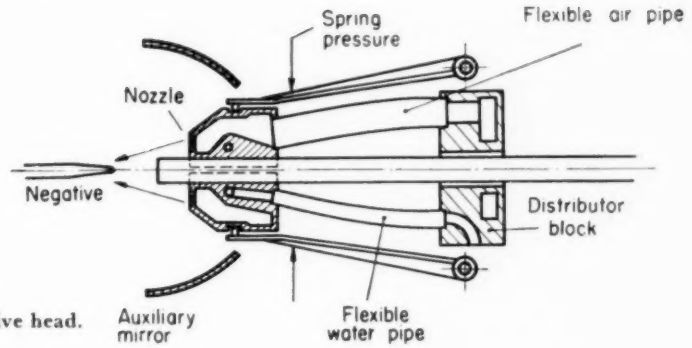


Fig. 4. Positive head.

of the metallic mirror with regard to these sputtering effects.

Color Projection

Three-dimensional and wide-screen projection must be combined with color. Since the picture is so much more realistic, the very best color has to be provided, and any color errors are much more noticeable than with a normal two-dimensional picture.

With subtractive color, the color quality is directly related to the transparency of the film, in such a way that really good color is only available with prints of high density. This is true as long as such dyestuffs as change saturation and hue with varying density are used for subtractive color.

Since color for three-dimensional and wide-screen projection has to be of the highest quality, it would not be practical to try to obtain more screen light for these processes by making color prints of higher transparency than that usual today for normal two-dimensional pictures.

Progress in Design Since 1950

In an earlier article[1] the author described a Ventarc giving a maximum output of 30,000 screen lm with 100 amp. The Super Ventarc presently described shows substantial progress in comparison with the technique used in 1950. The main improvements may be summarized as follows:

1. The Super Ventarc is provided with a magazine feed for the positives for continuous burning of the arc. Relatively short carbons can be used with this operation, thus giving better basic conditions for the optical illumination system. The 45° deflection mirror used with a vertical carbon in the earlier lamp can thus be avoided, and the positive is now arranged in the conventional horizontal position.

2. The design of the positive head has been improved by separating the carbon guide from the contact pieces, so that the centering of the positive is no longer affected by any wear of the contact pieces. These contacts are shaped as half cylinders, are directly water cooled, and each incorporates an air nozzle. Water, arc current, and compressed air are fed to the two contacts through flexible connections from a central distributor block. The carbon guide pieces are assembled with this block to form a stable unit. The contact pieces are pressed against the positive by a spring system which allows the contacts to adhere perfectly to the surface of the positive, without influencing the correct centering of the carbon (Fig. 4).

[1] Edgar Gretener, "Physical principles, design and performance of the Ventarc high-intensity projection lamps," *Jour. SMPTE, 55:* 391–413, Oct. 1950.

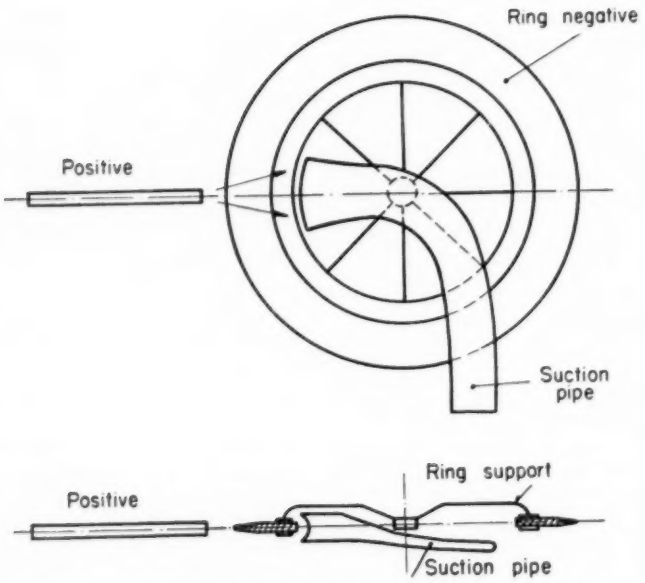


Fig. 5. Negative electrode.

3. The big negative ring used in 1950 which surrounded the positive head is now replaced by a much smaller one, located entirely at the negative side of the arc, and penetrating the elliptical reflector through a suitably shaped slot. With the metallic reflector used, this proved to be possible without sacrifice of the optical precision.

Figure 5 shows the negative-electrode arrangement, in which a suction pipe picks up the hot arc gases at the inner side of the ring negative. This arrangement permits a very simple design of the negative support and its driving mechanism.

4. As the main reflector, together with the auxiliary mirror, embraces the total solid angle round the arc stream, the front part of the positive head and the main reflector are not directly accessible for inspection and cleaning. For this reason, the whole negative part of the lamp mechanism, including the main reflector, the suction pipe and the negative drive is arranged to swing out around a vertical axis, thus giving the very best accessibility to all the important parts requiring service attention. The suction pipe is designed to go through this axis of rotation, so it need not be disconnected.

5. The blower producing compressed air for the positive head and suction for the negative pipe is arranged at the top of the lamphouse. It is driven very smoothly and silently by an induction motor. The lamphouse is ventilated by an ejector system driven by the exhaust of the suction pipe. This design proved to be more effective and less costly than the ejector system used in 1950. Furthermore, it avoids the necessity of providing additional blowers outside the lamphouse.

6. The heat filter has been arranged in a slide near the dowser, so that it can easily be taken out for inspection and cleaning.

The main reflector of the Super

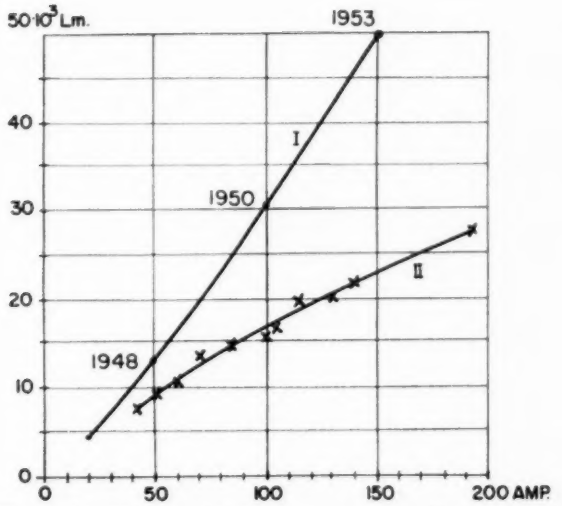


Fig. 6. Screen lumens, side-to-center ratio 80%: I, Ventarc lamps; II, conventional reflector-type arcs (NCC).

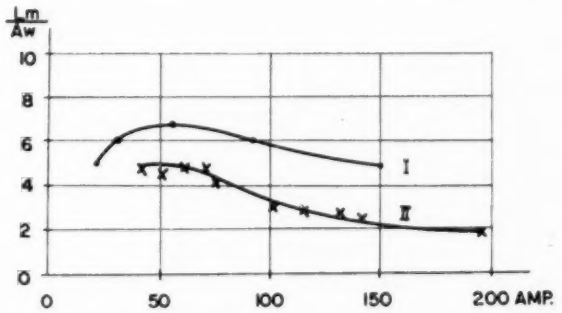


Fig. 7. Lumens per arc watt: I, Ventarc lamps; II, conventional reflector-type arcs (NCC).

Ventarc has been enlarged to a diameter of 24 in. This gives the necessary space for the positive head with the auxiliary mirror, the ring negative and the magazine feed for the positives, without causing any substantial light losses due to shadow masking of the illumination beams.

The big lamphouse associated with the 24-in. mirror gives the necessary safety margin for operating the arc, even with extremely high load.

The Screen Light From the Super Ventarc

Figure 6 gives the screen lumens of the Ventarc Lamp in which the range between 100 and 200 amp is covered by the Super Ventarc (SVA). It will be noted that a screen lumen level of approximately 50,000 lumens without shutter has been attained at 150 amp. Screen lumens per arc watt (lm/arc w) are plotted in Fig. 7. This value represents

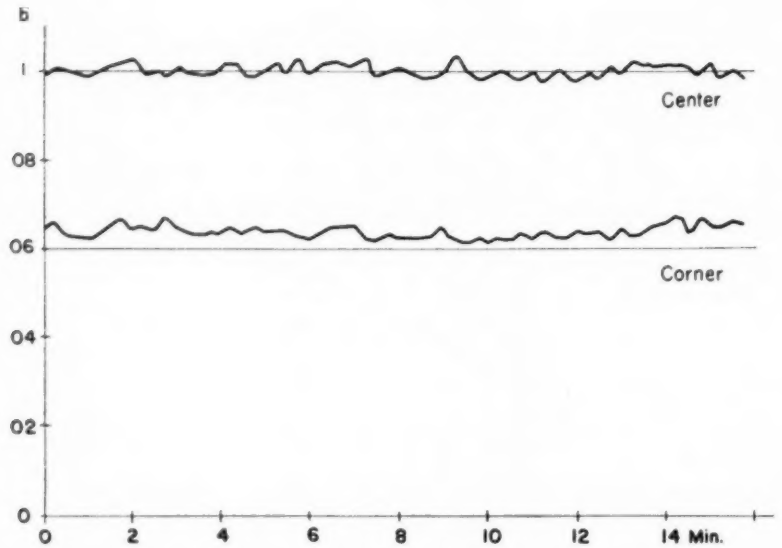


Fig. 8. Super Ventarc, 150 amp, screen light variations with time; b, relative brightness.

a figure of merit for the efficiency of the arc lamp. The distinction between arc watts as involved here, and the aperture watts used in earlier lumen-per-watt calculations should be noted. For comparison, the corresponding figures for conventional reflector-type arc lamps are plotted in the same diagrams. These figures have been taken from the paper by Holloway, Bushong and Lozier,[2] giving a survey on screen illumination with carbon arc 35mm motion-picture film projection systems. It should be noted that the most powerful arc of conventional type described there, run with 195 amp and giving 28,000 screen lumens with a side-to-center distribution of 80%, is only an experimental one. In contrast, the Super Ventarc figures stand for performance values which can be guaranteed for practical use.

The screen light from the Super Ventarc is homogeneous over the screen with regard to its spectral composition. The red-to-green ratio of the light measured at center, sides and corners of the screen shows no variation exceeding the measuring precision. This homogeneity is of importance for the projection of high-quality color films.

The screen light variations with time for center, sides and corners of the screen are shown in Fig. 8. It is seen from this diagram that the Super Ventarc meets the highest requirements which may be set up for three-dimensional and wide-screen projection regarding stability of screen illumination.

[2] F. P. Holloway, R. M. Bushong and W. W. Lozier, "Recent developments in carbons for motion-picture projection," *Jour. SMPTE, 61:* 223–240, Aug. 1953.

(*See page 532 for Convention discussion of this paper.*)

Performance of High-Intensity Carbons in the Blown Arc

By C. E. GREIDER

The performance of carbons operated in the Gretener type of "blown arc" shows the following advantages as compared with the more usual method of burning: (a) from 5 to 25% less current is required to produce the same light; (b) at the higher brightness levels, less carbon consumption is required for the same light; (c) the maximum light that the carbon will deliver is increased by 10 to 20%; and (d) uniformity of brightness across the face of the arc crater is considerably improved. The performance advantages of the "blown arc" seem to be considerably greater for 12-mm than for 10-mm carbons, and are greatest when the carbon is operated at or near its maximum current and light output. The addition of blowing to the arc introduces special problems regarding the design and operation of the negative electrode.

THE "blown arc" as described by Gretener[1] is strikingly different in appearance from the more usual form of the high-intensity carbon arc. The object of the present work was to determine whether this change in the shape and appearance of the light source produces a change in its light output, and more specifically, its effect on the relationship between light output, arc current and rate of consumption of the positive carbon.

Presented on October 9, 1953, at the Society's Convention at New York by C. E. Greider, Research Laboratories, National Carbon Co., a Division of Union Carbide and Carbon Corp., Cleveland, Ohio.
(This paper was received August 31, 1953.)

In the Gretener "blown arc," the positive carbon is surrounded by a magnet coil to "homogenize" the arc, together with a ring of air jets which direct a conical stream of air inward toward the arc. The latter changes the character and direction of the arc flame so that, instead of curving upward as it leaves the arc crater, it is concentrated and projected straight forward from the crater. The negative electrode is directly in front of the positive, in the path of this arc flame, which without the blowing would give an extremely unsteady arc at the high currents used. If a carbon rod of the customary shape is used for the negative electrode, deposits of carbon or rare earth carbide tend to form on its tip,

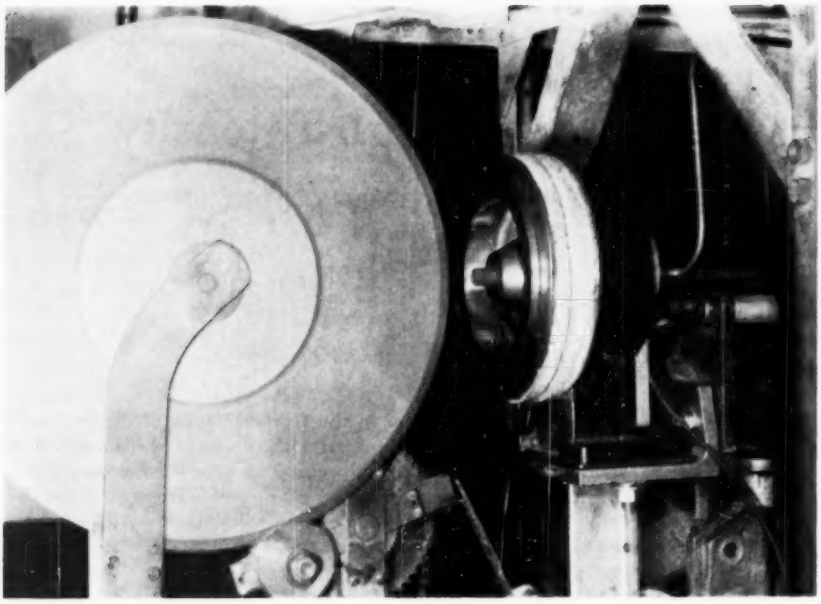


Fig. 1. Arc lamp mechanism for the "blown arc," using 12-mm positive carbons and a graphite disk negative.

causing unsteady operation. This can often be alleviated by small changes in the composition of the negative carbon or in its alignment. A preferred solution may be the substitution of a slowly rotating graphite disk as the negative electrode, as described by Gretener.[1] This does away with the formation of either mushroom carbon or rare earth carbide on the negative, but it is too early as yet to say whether it has eliminated all the problems associated with the negative electrode that are introduced by the addition of blowing to the arc.

Figure 1 shows the "blown arc" mechanism installed in an experimental test lamp, using the graphite disk negative. Figure 2 is a photograph of the "blown arc" in operation, using the same negative with a positive carbon of 12-mm diameter. The arc length is held at 15 mm, and the protrusion of the positive carbon from its holder is also 15 mm.

Since this work was designed to evaluate the effect of blowing, measurements with the same carbons were also made without blowing, keeping all other operating conditions the same as in the "blown arc" so far as possible. The same experimental test lamp was used, with silver water-cooled jaws previously described,[2] since water-cooled jaws are also used in the "blown arc" in order to obtain maximum performance from the high-brightness carbons used. The same positive protrusion of 15 mm was maintained. The angle between the axis of the negative and positive carbons was 53°, which when the arc is operated without blowing, seems to give the best performance with the carbons and arc currents used.

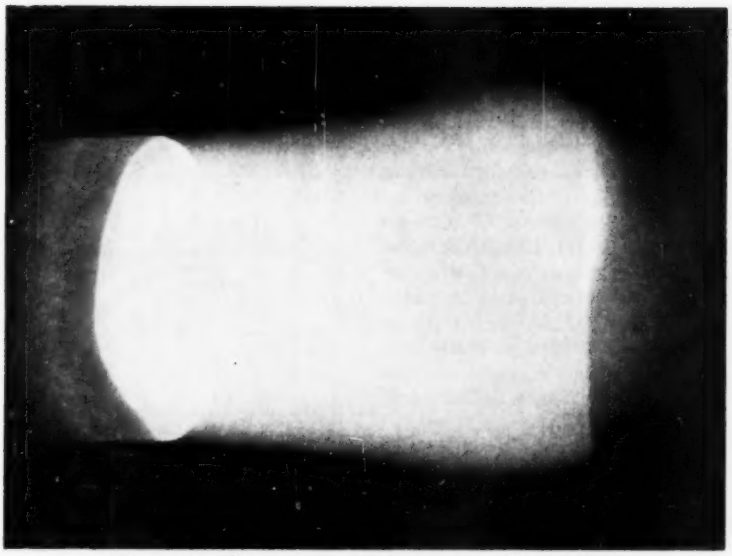


Fig. 2. The "blown arc," with 12-mm positive carbon and graphite disk negative.

Methods of Light Measurement

The light output with or without blowing was measured directly in terms of brightness at the crater of the arc, without consideration of any particular optical system. Direct crater-brightness measurements have the advantage of showing changes in brightness distribution across the crater face, which demonstrate more clearly the causes of observed differences in total light output. They can also be used to predict with reasonable accuracy the projection performance in any assumed optical system.[3]

All the measurements of arc-crater brightness were made at an angle of 50° from the axis of the positive carbon. Both the brightness and the light output of the arc crater will vary with angle of view; the choice of 50° represents a reasonable midpoint, since a typical mirror system will collect about the same amount of light in the outer zone beyond 50° as it will in the zone inside this angle.

Where the "blown arc" is shown by these measurements to have an advantage over conventional operation, this advantage may be greater in terms of screen light than is shown in the comparisons of crater brightness at 50° if a mirror with a large collecting angle is used. In the "blown arc," considerably more light is generated in the space directly in front of the crater. Measurements limited to crater brightness do not indicate the contribution which this cone of light in front of the crater can make to the total screen light, especially the light collected by the outer zones of the mirror, or by an auxiliary mirror.

The brightness across the crater face was measured by the method described by Jones, Zavesky and Lozier[4] in which a photocell is driven across a projected image of the crater, in synchronism with a recording meter which is calibrated (with the photocell) to give a direct reading of intrinsic brightness. Curves of crater brightness versus position are thus obtained across the crater face both

horizontally and vertically through the center of the crater image. From these curves, the maximum and center brightness can be read directly, and the average brightness can be readily calculated. To facilitate comparison, this average brightness is calculated only for a circular area of 10-mm diameter centered on the crater, when using 12-mm carbons or 8-mm diameter with 10-mm carbons. Because of the greater spindle in the "blown arc," the actual diameter of the arc crater will be only a few tenths of a millimeter larger than that of the area used for measurement of brightness.

This average brightness is independently determined by a second method suggested by Gretener, in which the entire image of the crater is projected onto the face of a photocell, using a much lower magnification than in the preceding case. The photocell is masked so as to admit only the light from the central 8 or 10 mm of the crater. Since the crater is viewed from an angle of 50°, this mask is elliptical rather than circular. These two methods of measuring crater brightness give excellent agreement, the difference between them being no more than 2 or 3%.

The Carbons

The comparisons reported below were all carried out with experimental carbons similar to the high-brightness type (Ultrex) carbons whose performance characteristics were recently described by Holloway, Bushong and Lozier.[5] A few comparisons made with carbons not designed to give so high a brightness have shown that blowing has about the same effect on performance as with these "high-brightness" carbons. Two different sizes of carbons were used, having diameters respectively of 10 and 12 mm. The 10-mm carbon is the one used in the "Super-Ventarc" described by Gretener in this issue of the *Journal*, while the 12-mm carbon has been used experimentally in the projection of

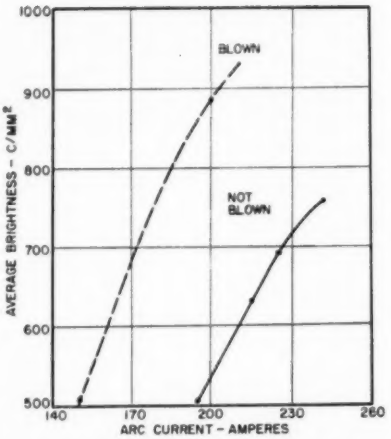


Fig. 3. Reduction in current requirement with "blown arc" operation. 12-mm high-brightness carbons.

theater television by the Eidophor process. With each carbon size, the core size and composition were selected to give the best efficiency in terms of current requirement and carbon consumption, consistent with steadiness of operation.

Comparative Results

The most outstanding and consistent effect of blowing is the lower current that is required to give the same light (or average crater brightness). This has been found true for all grades and sizes of carbons that have been examined. The magnitude of the difference is shown in Fig. 3 for the 12-mm high-brightness carbon. With this particular carbon the decrease in current required is from 30 to 40 amp or from 15 to 20%.

One reason for the lower current requirement in the "blown arc" is the smaller diameter of the arc crater at either the same current or the same brightness. This is caused by the air jet, which increases the oxidation or spindle on the outside of the shell. The amount of this difference will depend on

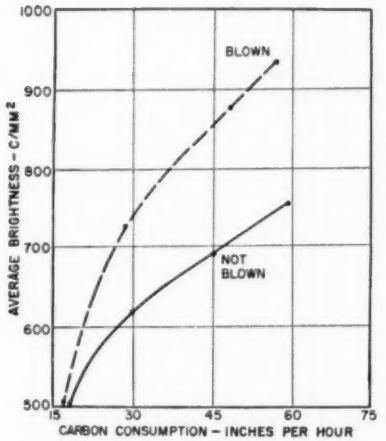


Fig. 4. Effect of "blown arc" operation on carbon consumption. 12-mm high-brightness carbons.

operating conditions, but for 12-mm carbons the "blown arc" at the same brightness will have a crater from $\frac{1}{2}$ to 1 mm smaller in diameter than obtained without blowing. A lower arc current will, therefore, be required with the "blown arc" to give the same current density at the crater, because of the smaller crater area over which the current is spread.

This smaller crater diameter, however, is not enough in itself to account for all the decreased current requirement. The effect of this factor can be eliminated by decreasing the shell thickness of the carbon when operated without blowing in order to compensate for the extra carbon that is burned away in the "blown arc," keeping the carbons otherwise identical.

Such a comparison shows that the smaller crater diameter of the "blown arc" is responsible for less than half of the decrease in current requirement. The rest may be due to the effect of the air jet in keeping the arc off the sides of the carbon, so that all the current is discharged in the crater itself. An alternative explanation is that the redirection of the arc flame produced by the blowing permits more effective utilization of the light-giving material (rare earth vapors) in the production of usable light.

The "blown arc" also requires lower carbon consumption for the same light output, especially at high levels of average brightness. This comparison is shown in Fig. 4 for the same 12-mm carbons of Fig. 3. The carbon consumption is about the same for either type of operation at an average crater brightness of 500, but as brightness is increased beyond this point, the "blown arc" shows increasingly greater superiority. It can also be run at a higher level of average brightness. This highest brightness obtained with this carbon without blowing (as normally operated) was no more than about 800 cp/sq mm, while in the "blown arc" it can readily be made to exceed 1000 cp/sq mm.

The principal reason for the higher average crater brightness with the blown arc is a much more uniform brightness distribution across the crater face. The light intensity at the point of maximum brightness is little if any higher, but a larger proportion of the total crater area equals or approaches this maximum brightness. This is illustrated in the curves for brightness distribution across the crater face for the two types of operation, shown in Fig. 5. At the point of maximum brightness near the center of the crater, both carbons show the same brightness of about 1400 cp/sq mm. Without blowing, however, the brightness falls off much more rapidly as the crater edge is approached. The "blown arc," therefore, can give much higher average crater brightness for the same center or maximum brightness.

The curves of Fig. 5 show also that with our conditions of measurement, the greatest improvement in uniformity and increased light output from the "blown arc" appears in the brightness curve measured in a horizontal plane through the crater. This gives a clue to the reason for the improvement.

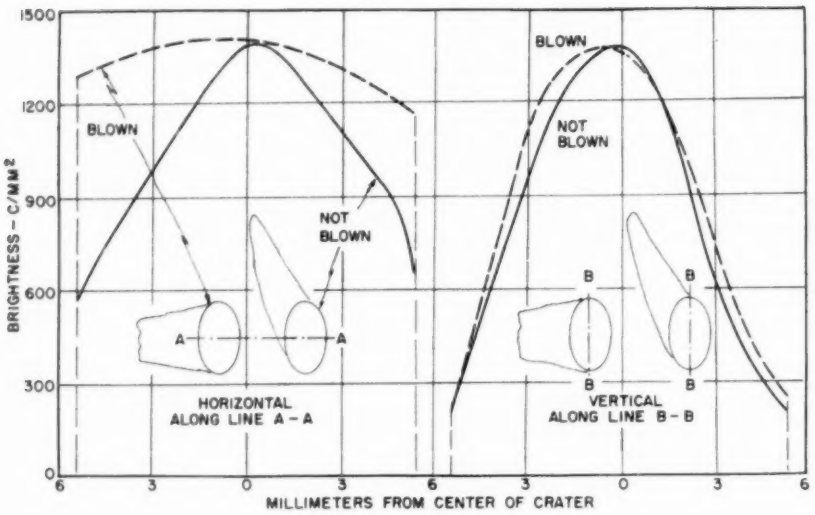


Fig. 5. Brightness distribution across the crater face with "blown arc" and conventional operation. High-brightness carbons with same core and crater size.

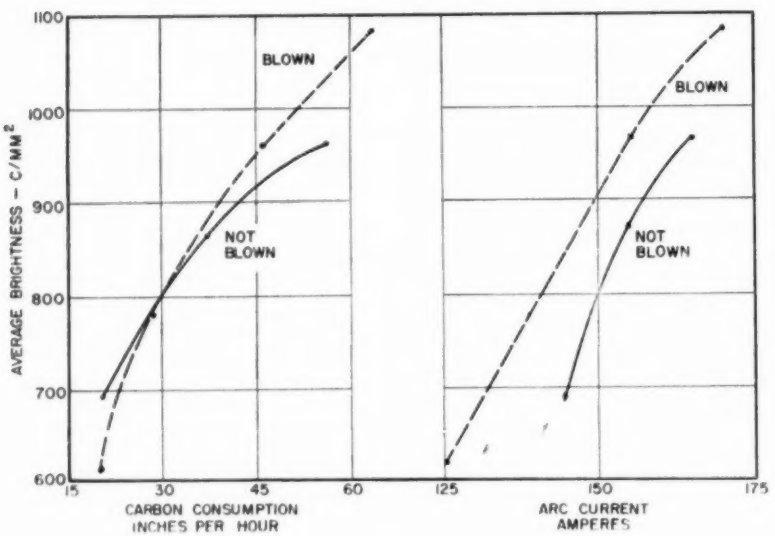


Fig. 6. Effect of "blown arc" operation with 10-mm high-brightness carbons.

Table I. Performance of "Ultrex" Type Carbons in the Blown Arc.

	Current, amp	Arc voltage	Carbon consumption, in./hr	Avg crater brightness cp/sq mm
10-mm carbons	125	60	20	610
	140	63	28	780
	155	71	46	960
	170	78	64	1080
12-mm carbons	150	55	17	505
	175	64	28	725
	200	71	48	875
	210	75	56	935

Without blowing, the "tail flame" is directed upward and away from the arc, and most of its light is not used, as shown in the sketches of the arc image in Fig. 5. In the "blown arc" this flame is concentrated and projected straight forward from the crater. Even if only crater brightness is measured, the brightness along the horizontal plane A–A is built up considerably by this addition from the arc flame, while if the optical system is so designed as to pick up light effectively from the area in front of the crater, the increase in usable light may be even greater. The increase in light appears principally in the horizontal brightness distribution curve because the 50° angle of view was in a horizontal plane with respect to the carbon axis; if the angle of view had been in a vertical plane, the increased light would have been mostly in the vertical brightness distribution curve.

The advantages of the "blown arc" seem to be somewhat greater with 12-mm carbons than with the 10-mm size. A typical comparison with 10-mm high-brightness (Ultrex) type carbons is shown in Fig. 6. It is seen from this that with the "blown arc", less current is required to produce the same brightness, but that the difference between the two is not as great as with the larger size. The 10-mm carbon as a "blown arc" does not show lower carbon consumption for the same brightness until the average crater brightness exceeds 800 cp/sq mm. As with the 12-mm carbon, the advantage in carbon efficiency increases as the brightness is increased, and the carbon is able to reach a higher average brightness in the "blown arc" than without blowing.

The light output of the "blown arc" is affected to some extent by operating conditions such as the strength of the applied magnetic field, the air pressure in the stabilizing air jets, and the effectiveness of the water cooling at the positive carbon jaws. Normally, however, variation of these factors which still permits satisfactory "blown arc" operation will not affect light or carbon consumption by more than about 5%. Typical values for current, carbon consumption and light (average crater brightness) are given in Table I for the 10- and 12-mm high-brightness type of carbons operated in the "blown arc."

The results of this work lead to the conclusion that "blown arc" operation permits a carbon to deliver considerably more light and to deliver the same amount of light at both a lower current and a lower rate of carbon consumption. Its advantages seem to be greater with 12-mm than with 10-mm carbons, while with a given carbon the superiority of blowing is greatest at the highest light output the carbon is capable of delivering. This type of operation should, therefore, find its greatest usefulness in conditions requiring an extremely high light output.

References

1. Edgar Gretener, "Physical principles, design and performance of the ventarc high-intensity projection lamps," *Jour. SMPTE, 55:* 391–413, Oct. 1950.
2. M. T. Jones and F. T. Bowditch, "Optimum performance of high-brightness carbon arcs," *Jour. SMPE, 52:* 395–406, Apr. 1949.
3. M. T. Jones, "Motion picture screen light as a function of carbon-arc-crater brightness distribution," *Jour. SMPE, 49:* 218–240, Sept. 1947.
4. M. T. Jones, R. J. Zavesky and W. W. Lozier, "Method for measurement of brightness of carbon arcs," *Jour. SMPE, 45:* 10–15, July 1945.
5. F. P. Holloway, R. M. Bushong and W. W. Lozier, "Recent developments in carbons for motion-picture projection," *Jour. SMPTE, 61:* 223–240, Aug. 1953.

Discussion on "An Improved Carbon-Arc Light Source for Three-Dimensional and Wide-Screen Projection," by Edgar Gretener

[After the paper, E. I. Sponable of Twentieth Century-Fox announced that the model on display was the first factory model and that its operation would be demonstrated later at the Twentieth Century-Fox laboratory.]

David B. Joy (*National Carbon Co.*): Referring to Fig. 6, a value of about 50,000 lumens is indicated for the Ventarc lamp. This value is, as Mr. Frey pointed out, about twice as high as what is now available in many of our largest theaters. In view of this, it is natural to wonder what measurements have been made of the heat at the film aperture.

Mr. Frey: As Mr. Sponable has already explained, the lamp has only recently been finished, so the values shown in the figure may not be final, but may be indicative. At exactly 150 amp we measured 48,000 lumens on the screen, that is screen lumens with a distribution of about 75%. In this case, the radiation energy at the center of the gate was 1.25 w/sq mm, which is about 30% less heat per unit of light than with the conventional arc. This radiation energy produces 48,000 screen lumens, while the same radiation energy for a conventional arc would be about 35,000 screen lumens.

Mr. Sponable: Some of you here might be interested in what we are going to do with a lamp of this type. It was originally designed for use with the Eidophor, and normally would have been finished when the commercial models of the Eidophor are ready later this fall. However, because we have the problem of showing CinemaScope on very large screens, particularly drive-ins, the use of such a lamp seems to be a possible solution for the drive-in problem.

Specifying and Measuring the Brightness of Motion Picture Screens

By F. J. KOLB, JR.

Screen brightness is measured and specified in order to control viewing conditions for projected pictures. By the modulation of light from the projector the whole artistic creation captured in the production of a motion picture is presented to its ultimate audience. This creation can only equal the director's concept when viewing conditions are known and predictable. The control of screen brightness and the screen-image transfer characteristic is therefore a necessary condition for the most effective presentation of motion pictures. Brightness characteristics of projected pictures are discussed and the various practical simplifications considered. Nine conditions of screen-brightness measurement are described, specifications for the meters required are developed, and several simplified practical procedures for field measurement are detailed.

In 1941 the Subcommittee on Screen Brightness of the SMPE Theater Engineering Committee undertook the job of determining how screen brightness should be measured and of specifying instruments suitable for the job, so that it would be more convenient to obtain data and study the viewing conditions of theater projection. Valid information on current practices, the Committee felt, was essential before any fundamental review of the 1936 temporary screen-brightness standards could be attempted, and before any improvement in theater viewing could be proposed.

Preliminary work led to specifications for an Illumination Meter and a Brightness Meter; these specifications were published in the October 1941 Committee report (*Jour. SMPE, 38:* 81–86, Jan. 1942).

Little progress was made during the war on the development of commercial instruments to meet these specifications. The problems of screen brightness had become of sufficient importance, however, that in the reorganization of the Society's committees, an independent Screen Brightness Committee was established in 1946. In March 1947 the Committee agreed to go ahead with what

A report prepared by the Subcommittee on Instruments and Procedures of the SMPTE Screen Brightness Committee. Subcommittee members are W. F. Little, A. Stimson, H. E. White and F. J. Kolb, Jr., Chairman. (Received for publication September 21, 1953.)

Note: Nomenclature throughout this report follows ASA Z7.1-1942, "Illuminating Engineering Nomenclature and Photometric Standards."

instruments were available, and determine the operating conditions in a small sample of theaters, in order to know what conditions would have to be met in a larger theater survey, to find out how well available instruments would perform, and to determine the practicality of surveying a significantly large number of the theaters at that time. Results of this preliminary survey were published in the Committee report of October 1947 (*Jour. SMPE, 50:* 254–276, Mar. 1948).

During the next four years the Committee had several instruments submitted for test, considered the limitations of equipment used in the 1947 survey, discussed what additional specifications should be formulated, and then undertook an enlarged theater survey using pilot-model instruments. The results of this survey eventually included more than 125 indoor theaters, divided among the various sizes of commercial theaters and located in several national geographic areas; data were published in the Committee reports of May and October 1951 (*Jour. SMPTE, 57:* 238–246, Sept. 1951; and *57:* 489–493, Nov. 1951).

At the Committee Meeting on February 2, 1950, a Subcommittee on Instruments and Procedures was appointed to review the problems of instrumentation and measurement. From the beginning it has been the purpose of this Subcommittee to express the instrumentation requirements for screen-brightness research and control, rather than to describe existing equipment. At succeeding meetings, the proposals of this Subcommittee have been discussed, modified and the intent re-examined, so that this report is presented as a statement and review of needs as they are presently understood.

Significance of Screen Brightness

Motion-picture films provide a form of visual art and communication dependent entirely upon the modulation of light. There is a sharp break in the presentation of motion pictures between the creative, preparatory work that produces a final image on motion-picture film, and the subsequent task of presenting this creation to the audience for whom it is intended. The director, producer and their staff cease any supervision of the project and turn the whole material over to the projectionist for him to present. Working solely with light to convey the visual content of this motion-picture film, the projectionist is concerned with the production of light, its concentration on the film, its modulation by the varying densities of the image, its collection in the projection lens, its reconvergence in an enlarged version of the photographic image, its re-emission from the projection screen, and finally its perception by the audience.

The eventual success of the creative thought and work producing a motion picture is dependent upon the successful modulation of the projection light in the exact manner visualized by the director when he approved the final work print. Yet many factors in the final presentation are subject to wide variation, beyond the director's control. The maximum brightness of the highlight areas in the picture as perceived by the audience is limited by the attainable screen brightness when the projector is operated with clear film in the gate; the minimum brightness of the shadow areas is limited by the stray and re-reflected light reaching the screen when the projector images an opaque target. Furthermore, the color of the screen light influences the faithfulness of screen reproduction, and the screen environment has great effect upon the illusion. These and similar factors together control the apparent contrast and mood of the picture, modify the highlight and shadow detail, determine the intelligibility of the picture information, and affect the psychological impact of the images.

The artistic creation may be presented effectively or poorly depending

upon the control of the many factors of screen brightness, and upon their agreement with anticipated values. The present success of projected pictures is evidence that much has been accomplished; even these successes have pointed out that much more is yet to be done.

Characteristics of Screen Brightness

Brightness of motion-picture screens is at first approach a simple subject and most of the measurements, treatments, and surveys have made enough assumptions to realize this simplicity. When the complete problem is considered, however, there are many interacting physical factors that determine the ultimate audience perception of the visual image. While simplification is often permissible and even desirable, *it is important to know at all times what assumptions have been made, and to remember that the brightness at a particular point on the motion-picture screen and the brightness differences across the screen depend upon the projector, the motion-picture film, the auditorium, the screen and the position of the observer.*

Considering a single point on the screen, the *brightness at that point* depends upon (1) the brightness of projection source and the transmission loss, determined by the projection equipment; (2) the loss during transmission of the beam to the projection screen (which is usually negligible) and the gain in brightness resulting from auxiliary lighting in the auditorium and re-reflections of screen light and flare of projected light (which altogether may be appreciable); (3) the reflection characteristics of the screen, including not only its efficiency but also its response to incident illumination at an angle which is seldom 90°, and its ability to direct energy along the variable reflection angle toward the particular spot occupied by the observer in the audience. For any single observer in the audience the *distribution of brightness across the screen* depends further upon (4) the brightness distribution in the projection aperture; (5) the pattern of photographic density on the motion-picture film; (6) the characteristics of the projection optics; and (7) the variation in angles of incidence and reflection from various portions of the screen surface.

Relatively constant factors in this grouping are determined for any particular theater by the equipment and the theater design. For example, the brightness of the projection source and the transmission losses of the complete optical system are practically constant for any measurements made in one specific theater. The gain in screen brightness from surround illumination and re-reflected light, has a constant component from the specific auditorium lighting, plus a variable component representing the re-reflected screen light. (This re-reflected light, of course, varies with changes in the subject matter on the screen.) The distribution of light incident upon the photographic image in the projection aperture is roughly predictable from the type of projection equipment and the details of its alignment and adjustment. (This distribution, however, may vary significantly with changes in the position of the carbons. With some equipment this variation is noticeable only if the arc control point tends to wander during the operating cycle; other equipment may be optically so critical that even constant attention of the projectionist to this one part of his duties may be insufficient to avoid measurable and noticeable changes in brightness distribution.)

Chief variable factors are those which depend upon observer position in the audience, and of course upon density distribution in the photographic intermediate.

For any projection screen the importance of specifying the angles at which light reaches the screen from the projector and the angles through which

light is reflected to reach the observer can be of extreme importance, as shown by Berger,[1] and D'Arcy and Lessman.[2] Many times it has been assumed that motion-picture screens are perfect diffusers whose brightness is constant for all directions of viewing. It is further usual to go beyond the original limitations defining such diffusion, and to assume that the brightness is constant in all directions even though the screen is illuminated at some angle other than the normal to its surface. While some of the common motion-picture matte screens approximate such a behavior, it has been shown that many of the commercial matte screens are measurably different — and actually that many screens are purposely designed to differ from such a perfect diffuser. Data presented by Lozier[3] show some commercial use of directional screens in motion-picture theaters; their use is presumed to be even more common in schools, industrial auditoriums, etc. Both the search for higher screen brightnesses together with the development of practical commercial procedures for making directional screens may be expected to produce a more widespread use of such materials. Directional screens offer the advantage of controlling brightness as a function of the angles of incidence and reflection; they are difficult to measure and evaluate for the same reason. In any installation, the angles of incidence and reflection vary significantly for different areas on the screen from any one observer position, and they usually vary even more from one observer position to another in the audience.

During the SMPTE screen-brightness surveys the theater screens were examined visually for evidence of directional reflection, but the classification was qualitative. It was possible, for example, to recognize the metalized screens, and data in these theaters are so identified. In most of the other theaters, however, directional effects of lesser magnitude presumably were not determined because the portable equipment commonly available does not conveniently provide the data for describing such screens.

Variations in subject matter — and therefore of image transmission and distribution — are, of course, not usually determined by theater survey; this information can be obtained more conveniently through laboratory measurements of properly chosen samples. In this report we shall limit ourselves to pointing out the importance of such information, together with the present lack of adequate data. Obviously it is never intended that the audience view a "bare screen," and bare-screen brightnesses have no direct significance! Projected pictures themselves are the true interest of audiences, and the brightnesses of the pictures themselves are basically what measurement seeks to determine, and what standards intend to control. It may be true that variations in film transmissions and in other factors relating bare screen to picture brightnesses occur less frequently, but they can be of considerable magnitude and it must be realized that they can appear at any time.

Despite the convenience and frequent necessity of separating the film-transmission variable from the other factors, it has been shown that our knowledge of transmission factors is inadequate.[4] This Committee recommends that a thorough study of picture densities be undertaken as an essential part of the screen-brightness problems. Particularly when the motion-picture engineer calls upon those in other fields for assistance (as he must in any problem so complex as the viewing of projected pictures) it is important to delineate the assumptions and definitions of our common ground.

Finally, in this group of variables of unusual significance, one must always realize that the problem of screen brightness is at its simplest still a problem of

tone reproduction. Not only is the maximum brightness of importance, but also the minimum brightness — and the nature of the brightness scale in between. Control of screen brightness implies control of a transfer characteristic, relating the screen image to the original creative visual sensation. It has been customary to simplify the problem by assuming that control of maximum brightness simultaneously controlled the shape of the entire transfer characteristic, and for a certain class of theater designs there was a limited constancy. Projected pictures are now viewed under such a range of conditions, however, that all the assumptions on viewing conditions must be checked to confirm their validity.

Theater Measurement of Screen Brightness

To answer the practical need for data on the viewing conditions for projected pictures, and to determine whether a particular installation is operating within the range of standards and recommendations, field measurements are necessary. These data are customarily obtained under conditions that involve many assumptions, made because of instrument limitations, necessity for minimizing measurement times, necessity for portability and independence from laboratory facilities, and other factors of general convenience.

Table I summarizes some of the possible measurement procedures, specifies the cognate assumptions, and notes details of equipment and procedures. The more detailed measurements may be necessary for research workers; the less detailed measurements should interest practical projectionists.

The Appendix presents in more detail the specifications for the instruments themselves,* and for procedures for their use, recommended by the Screen Brightness Committee. In many cases these specifications include the best present compromise between what would be desirable and what it is practical to obtain. This summary is intended as a reference for the Committee and the industry on the determination of screen brightness data, and as a guide for those who may be interested in developing more suitable instruments.

APPENDIX

Instruments and Procedures for the Measurement of Screen Brightness

This presentation of instrument specifications and procedures for their use in the determination of motion-picture screen brightness has been prepared to provide more definite answers for two questions considered in the previous discussion:

1. What quantities are to be measured, and how are the measurements to be made?
2. What are adequate standards for judging the suitability of instruments?

Essentially the presentation is a formulation of the discussions and experience of the Screen Brightness Committee, although in some matters of detail it has been necessary to infer which of the possibilities is preferred.

The *Proposed Specifications*, presented below, for illumination, brightness, reflectance, and luminous flux meters describe instruments which do not necessarily exist.

* This memorandum was prepared before the widespread interest in three-dimensional projection using dual prints and polarized projection light; accordingly the instrument specifications do not include a discussion of apparent brightness for polarized viewers, or of determinations of depolarization. These problems are under study by another subcommittee of the SMPTE Screen Brightness Committee, which will make recommendations on these additional requirements of instrumentation and measurement.

Table I. The Procedures for Measuring Screen Brightness — A Summary of Necessary Assumptions and Desirable Instruments.

Condition	Assumptions	Instruments Applicable*	Procedure†	Notes
I	(1) None.	(1) Brightness meter, audience-type, high sensitivity, Spec. A.	(1) Measure screen brightness as a function of film transmission, of audience placement and of position on the screen.	(1) This information, or its equivalent, is the ultimate basis for screen brightness standardization. It is usually not practical to determine it directly.
II	(1) Effective film transmission known.	(1) Brightness meter, audience-type, high sensitivity, Spec. A.	(1) Measure screen brightness at selected, arbitrary film densities, as a function of audience placement and of position on the screen.	(1) This procedure is recommended for research studies of screen brightness.
III	(1) Effective film transmission known. (2) Nature of transfer characteristic known.	(1) Brightness meter, audience-type, high sensitivity, Spec. A.	(1) Measure brightness of the bare screen and of the shielded screen as a function of audience placement and of position on the screen.	(1) When the nature of the transfer characteristic for the installation being measured is known, then locations of the two ends of the curve determine the complete transfer characteristic.
IV	(1) Effective film transmission known. (2) Transfer characteristic known. (3) Relative brightness known as a function of projection angle and viewing angle.	(1) Brightness meter, audience-type, Spec. B. or (2) Brightness meter, screen-type, Spec. C.	(1) Measure from one location in the audience, determining brightness of the bare screen as a function of position on the screen. (2) Measure from immediately in front of the screen, determining normal brightness of the bare screen as a function of position on the screen.	(1) Calculation of apparent screen brightness as a function of viewing angle usually is not attempted; most frequently the screen is assumed matte, with brightness independent of viewing angle.

V	(1) Effective film transmission known. (2) Transfer characteristic known. (3) Relative brightness known as a function of projection angle and viewing angle. (4) Brightness of any point on the screen directly proportional to normal, incident illumination.	(1) Brightness meter, audience-type, Spec. B; *plus* illumination meter, screen-type, Spec. D. or (2) Brightness meter, screen-type, Spec. C; *plus* illumination meter, screen-type, Spec. D.	(1) Measure from one location in the audience, determining brightness of the bare screen at its center. Measure incident bare-screen illumination normal to the screen as a function of position on the screen. (2) Measure from immediately in front of the screen the normal, bare-screen brightness at its center. Measure incident bare-screen illumination normal to the screen as a function of position on the screen.	(1) This procedure was followed for the 1947 and 1950–51 Theater Surveys. (2) This procedure, or that for condition IV (depending upon instruments available) is the most complete that it is convenient to attempt in an operating theater.
VI	(1) Effective film transmission known. (2) Transfer characteristic known. (3) Brightness of any point on the screen directly proportional to normal, incident illumination.	(1) Illumination meter, screen-type, Spec. D *plus* gonioreflectometer, Spec. E.	(1) Measure incident bare-screen illumination normal to the screen as a function of position on the screen. Measure reflectance of the screen as a function of projection angle and viewing angle.	(1) Measurement of screen reflectance as a function of projection angle and viewing angle is usually attempted only in the laboratory on a sample of the screen material.
VII	(1) Effective film transmission known. (2) Transfer characteristic known.	(1) Illumination meter, screen-type, Spec. D *plus* reflectance meter, Spec. F.	(1) Measure incident bare-screen illumination normal to the screen as a function of position on the screen. Measure normal reflectance of the screen.	(1) This procedure was used as an alternate in the 1950–51 Theater Survey.

Continued on next page

Table I. Concluded.

Condition	Assumptions	Instruments Applicable*	Procedure†	Notes
	(3) Relative brightness known as a function of projection angle and viewing angle. (4) Brightness of any point on the screen directly proportional to normal, incident illumination.			
VIII	(1) Effective film transmission known. (2) Transfer characteristic known. (3) Relative brightness known as a function of projection angle and viewing angle. (4) Brightness of any point on the screen directly proportional to normal, incident illumination. (5) Screen reflectance known.	(1) Luminous flux meter, differential-type, Spec. G.	(1) Measure light flux leaving the projection lens, determining independently the flux in individual pencils of light directed to specific locations on the screen as a function of position on the screen.	(1) This is a practical serviceman's procedure for projector adjustment.

15	(1) Effective film transmission known. (2) Transfer characteristic known. (3) Relative brightness known as a function of projection angle and viewing angle. (4) Brightness of any point on the screen directly proportional to normal, incident illumination. (5) Screen reflectance known. (6) Distribution of incident illumination over the screen area known.	(1) Luminous flux meter, integral-type, Spec. H.	(1) Measure total light flux leaving the projection lens.	(1) This procedure is suitable for adoption as a routine check by projectionists in any theater.

Notes:

* When there are two types of instruments suitable for a given measurement (within the range of meter types specified in the Appendix) both are listed.

† When alternative instruments have been noted, two procedures are given also, corresponding respectively to the listing of the instruments

It has been the intention to prescribe instruments that are both essential and desirable, attempting to strike a balance between what the Screen Brightness Committee has found necessary and what can reasonably be manufactured. Obviously the more complex research instrument specifications make little concession to ease of manufacture, while the less complex practical instruments have no reason for consideration unless they can be widely available at reasonable prices. In every case it has been necessary to balance the probable use of the data, the magnitude of other measurement errors, and the estimated cost of more stringent specifications. In the opinion of the Committee, these compromises are the most desirable that can now be selected.

It is recognized further that much information has been accumulated and will continue to be obtained — with instruments that do not meet these specifications. This report is not intended to discredit these instruments or data derived with them, but only to provide a standard for their evaluation. By indicating what variables may have influenced the results, and cautioning against unwarranted assumptions and conclusions, these specifications may help to make more useful the data from such nonconforming instruments.

Recommended Procedures for the measurement of illumination, brightness, reflectance, and luminous flux follow the general outline of the Screen Brightness Committee's Theater Surveys. These procedures, it will be noted, are concerned only with the problems of practical theater measurement and not the more complex research activities. The more precise data for controlled studies will be obtained by relatively few workers who are deeply engrossed in the subject, and who will want to work out their own procedures. These recommendations are intended solely for those who must add the measuring of screen brightness to many other problems and interests, and who will use the simpler instruments of necessity; for their use the Recommended Procedures outline what measurements need be made and what instruments are required, plus necessary information on methods of measurement, calculations, and possible interference or complications.

At the beginning of the Committee's Theater Surveys it had been agreed that the measurement of screen illumination — convenient and straightforward — should be depended upon to provide the primary practical data, and that screen brightness should be calculated after determining a reflectance factor for computing brightness. It soon became obvious, however, that in many instances attempts to measure illumination at points on the screen a considerable distance above the stage or ground present real mechanical problems. On the assumption that auxiliary equipment sufficiently universal to position the light-sensitive elements of illumination meters properly in every theater installation will not be common, the Committee has also considered measurements of total luminous flux at the projector, in order to provide data that might otherwise be unobtainable. Finally, this report has been expanded to point out the real objective of screen brightness measurements, together with some of the pitfalls of oversimplification.

Index to Specifications

Spec.	Title	Page
A	Brightness Meter — Audience-Type — High Sensitivity	543
B	Brightness Meter — Audience-Type	544
C	Brightness Meter — Screen-Type	545
D	Illumination Meter — Screen-Type	546
E	Gonioreflectometer	547
F	Reflectance Meter	548
G	Luminous Flux Meter — Differential-Type	549
H	Luminous Flux Meter — Integral-Type	550

Index to Recommended Practices

Recommended Practice for the Determination of Bare-Screen Brightness	551
Recommended Practice for the Measurement of Luminous Flux	554

Specification A. Brightness Meter — Audience-Type — High Sensitivity*

1. Purpose. An instrument to measure brightness of a motion-picture screen, for use from the audience, and of adequate sensitivity to measure the range of brightnesses defining the transfer characteristic of projected motion pictures.†

2. Scope. This specification describes a light-sensitive cell which can be located within the audience area to receive the light reflected from a motion-picture screen's surface, a meter to indicate cell output, together with a suitable aiming device so that the brightness can be determined for a specific, small screen area.

3. Useful Range. 0.005–60 ft-L; multiple scales or logarithmic scale required.

4. Accuracy.

a. Initial Accuracy: ±7% of the scale point within the upper half of the scale, and ±7% of the midscale value within the lower half of the scale — measured at 70 F with tungsten light at a color temperature of 2700 K. Scales shall be so chosen that any brightness within the useful range can be read with an initial accuracy of at least ±15%.

b. Temperature Sensitivity: Any change in indication resulting from a temperature change of ±20 F from the reference temperature of 70 F shall not exceed 12%.

c. Fatigue: Negligible, providing cell has not been exposed to illumination in excess of 100 times the measured value within 10 min of measurement.

d. Color Response: The sensitivity shall correspond to the standard luminosity curve, such that the response curve of the cell shall be within that envelope whose ordinates are the standard luminosity curve ±5% of the maximum ordinate.

e. Integration: The meter is intended for use with 48- to 72-cycle illumination,‡ and a net integral shutter transmission of 30% – 70%. If under these conditions there is a frequency error a calibration curve shall be supplied.

5. Response. Meter period and damping shall be chosen to give a response time of less than 10 sec. Meter and cell shall be rugged, and resistant to a shock of 20 g.

6. Acceptance Angle. This meter shall be shielded so that the 50% cutoff from a point source occurs at an acceptance angle no greater than ±0.5°.

7. Operation.

a. Convenience: Instrument easily moved, located, and read by one man.

b. Power: Self-contained power would be preferred, although 110-v, 60-cycle, a-c operation may be required.

c. Support: Sufficient for use of meter from the seating area of the auditorium. The supporting and aiming device should indicate viewing angles sufficient to describe the audience positions from which measurements are made.

8. Probable Range of Values.

	Indoor Theaters		*Outdoor Theaters*	
	Max.	*Min.*	*Max.*	*Min.*
θ = Horizontal angle subtended by screen from theater midline	53°	9°	35°	6°
ψ = Horizontal viewing angle, to screen normal	±65°	0°	±65°	0°
α = Vertical viewing angle, to screen normal	+45°	−10°	+40°	+2°

Notes

* This meter is intended to provide direct data on the brightness of projected pictures, and therefore must be used for extended periods of measurement to determine the variations in brightness over the picture area and the variations with subject matter. It is primarily a research instrument.

† This meter will also be useful for measuring brightnesses of the screen surround, and of the audience areas of the theater.

‡ Since current practice overwhelmingly favors intermittent projection, the meters for measuring the brightness of motion-picture screens must integrate a series of light pulses. Usually 35mm projection equipment provides 48 pulses/sec, while 16mm projection equipment provides 72 pulses/sec at "sound speed" and 48 pulses/sec at "silent speed." The light pulses are interspersed with almost total darkness; light pulses are of approximately equal duration and are approximately equally spaced in time.

Specification B. Brightness Meter — Audience-Type*

1. Purpose. An instrument to measure brightness of a motion-picture screen from the audience area, of adequate sensitivity to measure the brightness of a bare screen.

2. Scope. This specification describes a light-sensitive cell which can be located within the audience area to receive the light reflected from a motion-picture screen's surface, a meter to indicate cell output,† together with a suitable aiming device so that the brightness can be determined for a specific, small screen area.

3. Useful Range. 0.2–60 ft-L. Multiple scales or logarithmic scale required.

4. Accuracy.

a. Initial Accuracy: Same as Spec. A.

b. Temperature Sensitivity: Same as Spec. A.

c. Fatigue: Negligible, providing cell has not been exposed to illumination in excess of 10 times the measured value within 10 min of measurement.

d. Color Response: Same as Spec. A.

e. Integration: Same as Spec. A.

5. Response. Same as Spec. A.

6. Acceptance Angle. This meter shall be shielded so that the 50% cut-off from a point source occurs at an acceptance angle no greater than ±1.5°.

7. Operation. Same as Spec. A.

8. Probable Range of Values. Same as Spec. A.

Notes

* This specification describes a meter suitable for measuring screen brightness when the projector is operated normally except that no film is threaded into the gate.

† Committee experience has indicated that it is highly desirable for this instrument to be direct reading; there are several meters available that nearly meet these specifications, but require the subjective balancing of two illuminated fields. In these existing meters, the two fields are usually of different colors and different observers frequently disagree in their choice of balance readings.

Specification C. Brightness Meter — Screen-Type*

1. Purpose. An instrument to measure point-to-point normal brightness of a motion-picture screen, of adequate sensitivity to measure the brightness of a bare screen.†

2. Scope. This specification describes a light-sensitive cell which can be located within a few feet of the screen face to receive the light reflected from a motion-picture screen's surface, a meter to indicate cell output, together with a suitable support to position the cell in the desired location in front of the screen.

3. Useful Range. Same as Spec. B.

4. Accuracy. Same as Spec. B.

5. Response. Same as Spec. A.

6. Acceptance Angle. This meter shall be shielded so that the 50% cut-off from a point source occurs at an acceptance angle no greater than ±35°; it is assumed that the meter will be used at a distance from the screen of 2–3 ft. For meters intended to be used at greater distances, the locus of the 50% cut-off shall enclose a screen area no larger than that permitted above.

7. Operation.

a. Convenience: Instrument easily moved, located, and read by one man.

b. Power: Self-contained power preferred.

c. Support: Support must be portable in a passenger automobile, it must be capable of being assembled and operated by one man, and it must support the cell at any location before the screen without danger of contact or injury to the screen surface.

8. Probable Range of Values. The following table lists the range of variables normally expected. Symbols refer to the drawing in "Recommended Practice for the Determination of Bare-Screen Brightness."

	Indoor Theaters		*Drive-In Theaters*	
	Max.	*Min.*‡	*Max.*	*Min.*‡
H Ft	30	9	52.5	22.5
W Ft§	40	12	70	30
N Ft	10	2	25	10
B_A Ft-L	30	4	20	2
B_C Ft-L	28	1	15	0.5
Reflectance %	100‖	35	80	30
Perforated Screen	Yes		No	

Notes

* This specification describes a meter of general usefulness, comparable in application and results to Specification B except that less information is obtained about the variations in brightness with changes in the viewing angles. The choice between these two meters will probably be made on the basis of availability, convenience and the frequency of occurrence of directional screens.

† This meter's practical usefulness is limited to the measurement of screens that are matte, or nearly perfect diffusers. Its results with directional screens can be interpreted accurately only after careful

calibration with the specific directional screen measured.

‡ The minimum value of brightness quoted in section 8 "Probable Range of Values" assumes low reflectance of the screen combined with measurements in a corner of the screen. If measurements are made at the geometric center, this minimum expected brightness can be increased by 100% or more.

§ These screen widths are based upon a picture aspect ratio of 1.33. At the present time there is consideration of larger aspect ratios at least up to 2.85, which may increase the values of "W" without changing maximum values of "H."

‖ Apparent reflectance values of 100% or more may occur with screens having some directional effect; in the 1951 Theater Survey several screens with apparent brightness gains up to 200% were found.

Specification D. Illumination Meter*

1. Purpose. An instrument to measure point-to-point illumination at the motion-picture screen, and to determine illumination distribution.†

2. Scope. These specifications describe a light-sensitive cell which can be located to intercept light falling on any part of a motion-picture screen's surface, a meter to read cell output located where it can be read by an observer at the base of the screen, and a support to position the cell in the desired place in front of the screen.

3. Useful Range. Low scale, 0.5–30 ft-c. High scale, 2–60 ft-c.

4. Accuracy.

a. Initial Accuracy: Same as Spec. A.

b. Temperature Sensitivity: Same as Spec. A.

c. Fatigue: Same as Spec. B.

d. Color Response: Same as Spec. A.

e. Integration: Same as Spec. A.

5. Response. Same as Spec. A.

6. Operation.

a. Convenience: Instrument easily moved, located, and read by one man.

b. Power: Self-contained power preferred.

c. Support: Support must be portable in a passenger automobile, it must be capable of being assembled and operated by one man, and it must support the cell at any point on the screen without danger of contact or injury to the screen surface. (If the support holds the cell at an appreciable distance forward of the screen, an inverse square law correction will need to be made on illumination values.)

7. Probable Range of Values. The following table‡ lists the range of variables normally expected. Symbols refer to the drawing in "Recommended Practice for the Determination of Bare-Screen Brightness."

	Indoor Theaters		*Drive-In Theaters*	
	Max.	*Min.*	*Max.*	*Min.*
H Ft	30	9	52.5	22.5
W Ft§	40	12	70	30
N Ft	10	2	25	10
E_A Ft-c	40	5	27	2.7
E_C Ft-c	37	1.3	20	0.7
Reflectance	100	35	80	30
Perforated Screen	Yes		No	

Notes

* This is considered the basic instrument for the practical measurement of projection conditions in the theater. At the present stage of instrument development, it appears that this instrument is most likely to be the one generally available.

† This specification describes a meter suitable for measuring screen illumination only. The Screen Brightness Committee, however, has indicated that eventually

some meter for measuring the illumination of the screen surround will be necessary in order to control picture perception. This meter plus that described in Spec. A are the only two appropriate — and this meter could be used only if its Useful Range could be extended to 0.01 60 ft-c. There is a slight advantage in measuring surround illumination rather than surround brightness, because most of the screen surround makes use of surfaces of low reflectance — and therefore measurements of illumination do not require as great sensitivity to low signal.

‡ This table is a restatement of the corresponding table in Spec. C, revised to give approximate illumination values instead of brightness values.

§ These screen widths are based upon a picture aspect ratio of 1.33. At the present time there is consideration of larger aspect ratios at least up to 2.85, which may increase the values of "W" without changing maximum values of "H."

Specification E. Gonioreflectometer*

1. Purpose. An instrument to measure specular reflectance† of motion-picture screens as a function of viewing angle, for use in conjunction with measurements of illumination.

2. Scope. This specification describes a light-sensitive element receiving light reflected from the screen, a standard source illuminating the screen (or provision to use a standard projector), a meter indicating response of the light-sensitive element, together with a mechanism for holding these components in proper relationship and indicating their relative angles.

3. Useful Range. Reflection factor 0.01 to 10.‡

4. Accuracy.

a. Initial Accuracy: Same as Spec. A.

b. Temperature Sensitivity: Same as Spec. A.

c. Fatigue: Same as Spec. A.

d. Color Response: Same as Spec. A.

e. Integration: If the meter is designed to provide its own standard source of illumination the source may be continuously excited and no intermittency problem results. If on the other hand the meter uses the light from a standard projector, its integration performance should be the same as Specification A.

f. Measuring Illumination. Reflectance shall be measured with light of a quality approximating a color temperature of 2700°K., or with light of high-intensity arc quality.

5. Response. Same as Spec. A.

6. Field of View.

a. Measuring Illumination: The incident illumination shall be specular, with the light confined to a cone of not more than ±0.5° included angle.

b. Acceptance Angle: The light-sensitive cell shall be shielded so that the 50% cut-off from a point source occurs at an acceptance angle no greater than ±0.5°.

c. Area Measured: The screen surface measured for reflectance shall be greater than 0.2 sq ft but less than 4 sq ft.

7. Angle of Reflection. The light-sensitive element shall be adjustable to measure reflectance through the range of illumination angles in section 9 of this specification and of viewing angles in section 8 in Spec. A.

8. Operation.

a. Convenience: Same as Spec. D.

b. Power: Self-contained power is preferred. If necessary for the proper balance of performance and portability

to use external power (for example to provide a self-contained source of illumination) an instrument operating on 110-v, a-c d-c can be used.

c. Support: Since it will be sufficient to measure reflectance at a limited number of locations on the screen, it will not be necessary to cover the full range of screen area required for Spec. D. It would be a convenience in many cases, however, to use the same support therein described.

9. Probable Range of Values. Same as Specs. A and C, plus:

	Max.	*Min.*
ϕ_V = Vertical projection angle	±25°	0°
ϕ_H = Horizontal projection angle	± 5°	0°

Notes

* There are two possible use patterns for a motion-picture screen gonioreflectometer: Measurement in the theater, and measurement in the laboratory. In either event it is expected that this will be primarily a research instrument, and that there will never be a great number constructed. At present it seems more likely that the laboratory usage is the more probable, and in this case the requirements that have to do primarily with portability (section 8 of this specification) can be disregarded. No other distinction between the two use patterns seems desirable.

† Specular Reflectance is important for motion-picture screen performance because for any one position on the screen, the base of the incident light cone is the exit pupil of the projection lens, and the base of the reflected light cone is circumscribed around the observer's eyes at any one viewing position. (Diffuse reflection is only useful as an approximation, when the screen surface is nearly matte and no investigation is made of angular distribution.

‡ A wide range of reflectance values may be expected. For matte screens there is variation from the low values of deteriorated screen surfaces, through the medium values of the weather-resistant surfaces of outdoor theaters, to the high values of new indoor screens. For directional screens there is variation from the very low values of off-angle reflection to the very high values in the direction of maximum efficiency.

Specification F. Reflectance Meter*

1. Purpose. An instrument to measure normal reflectance of motion-picture screens, for use in estimating brightness from measurements of illumination. Usefulness of this instrument is practically confined to the measurement of matte screens.†

2. Scope. This specification describes a light-sensitive element receiving light reflected from the screen, a standard source illuminating the screen, a meter indicating response of the light-sensitive element, together with a mechanism for holding these components in proper relationship.

3. Useful Range. 30–120% reflectance.

4. Accuracy. Same as Spec. E.

5. Response. Same as Spec. A.

6. Field of View.

a. Measuring Illumination: The incident illumination shall be specular, with the light confined to a cone of not more than ±1.5° included angle.

b. Acceptance Angle: The light-sensitive cell shall be shielded so that the 50% cut-off from a point source occurs at an acceptance angle not greater than ±1.5°.

c. Area Measured: The screen surface measured for reflectance shall be greater than 0.2 sq ft but less than 4 sq ft.

7. Angle of Reflectance. The light illuminating the screen shall be normal to its surface. The angle between the light-sensitive element and the normal

to the center of the test area shall be approximately 10°.‡

8. Operation. Same as Spec. E.

9. Probable Range of Values. Same as Spec. E.

Notes

* In contrast to the gonioreflectometer of Spec. E, this instrument is intended almost exclusively for use in the theater. Therefore, the requirements for portability, etc. cannot be compromised.

† It would be possible to study a particular motion-picture screen with more refined equipment to obtain a calibration so that this particular instrument's readings could be converted to a complete specification of angular response. The difficulties of this task, however, make it desirable to confine this meter to screens that may be considered diffuse scatterers.

‡ It would be a convenience if this instrument could measure interchangeably both the specular reflectance specified, and the total diffuse reflectance from the same light source. With such an instrument the two reflectances could be compared to indicate immediately when the screen was matte or directional.

Specification G. Luminous Flux Meter — Differential-Type*

1. Purpose. An instrument to measure luminous output at the projector, and to indicate the relative intensities of the pencils of light directed to specific locations on the screen. This meter is intended for use primarily when physical conditions and the instruments available prevent measurements at the screen.†

2. Scope. This specification describes a light-sensitive cell which can be located to intercept the total luminous output from the projection lens (or a predetermined portion of that total output), a meter to read cell output, and any necessary appurtenances for their use. Specifically included are necessary masks or other devices to be inserted into the projector aperture and focused on the screen,‡ in order to sample particular screen areas for measurement of light flux. This meter will be used either immediately at the lens exit within the projection booth, or immediately beyond the projection port just outside the projection booth.

3. Useful Range. 100–20,000 lumens§ multiple scales or logarithmic scales required.

4. Accuracy. Same as Spec. A.

5. Response. Same as Spec. A.

6. Scanned Area. As a minimum the meter must read luminous flux to each of the five measuring areas specified in "Recommended Practice for the Determination of Bare-Screen Brightness." Each pencil shall intercept at the screen no more than 1% of the illuminated screen area.

7. Operation.

a. Convenience: Instrument easily moved, located, and read by one man.

b. Power: Self-contained power preferred. 110-v, a-c will be available, however.

c. Support: In all cases the instrument and any supporting structures must be portable in a passenger automobile, transportable through a projection-room door, and it must be capable of being assembled and operated by one man. When intended for use within the projection booth any support must not interfere with the projector mechanism, or be limited by the front wall or port of the booth. When intended for use outside the projection booth, suitable support for the instrument to position it firmly will probably be required.

8. Probable Range of Values. The following table lists the range of variables normally expected. Symbols refer to the drawing in "Recommended Practice for the Measurement of Luminous Flux."

		Indoor and Outdoor Theaters	
Value		*Max.*	*Min.*
D	In.	4.00	2.03
S	In.	24	6
2α	Degrees	24°	5°
F	Lumens total flux	20,000	200
N	Ft	20	2

Notes

* This meter is relatively simple in operation and probably such that a regular projector serviceman could include it in his kit. There is much to be gained by research studies of screen brightness, but perhaps equally important is the practical gain from proper servicing of equipment; convenient measurement is a prerequisite for adequate servicing.

† Screen brightness and illumination are considered functions of the *masked area of the screen*, whereas this meter measures in terms of the *total illuminated area.* Any significant difference between masked and total area must be noted, because it will affect not only the total flux transmitted, but also the relative positions of the measuring areas sampled from the total screen.

‡ A standard projector aperture is assumed. Any departure from this standard must be noted.

§ These values of luminous flux are mean net values, integrated over a sufficient time to damp out the flicker of intermittent projection.

Specification H. Luminous Flux Meter — Integral-Type*

1. Purpose. An instrument to measure total luminous output at the projector when physical conditions prevent measurements of intensity and distribution at the screen. Because of the failure to provide some of the important data, this meter and method of measurement are proposed only to provide some information when otherwise there would be none available.†

2. Scope. These specifications describe a light-sensitive cell which can be located to intercept the total luminous output from the projection lens (or a truly representative portion of that total output),‡ a meter to read cell output, and any necessary appurtenances for their use. This meter will be used either immediately at the lens exit within the projection booth, or immediately beyond the projection port just outside the projection booth.

3. Useful Range. 1000–20,000§ lumens.

4. Accuracy. Same as Spec. A.

5. Response. Same as Spec. A.

6. Operation. Same as spec. G.

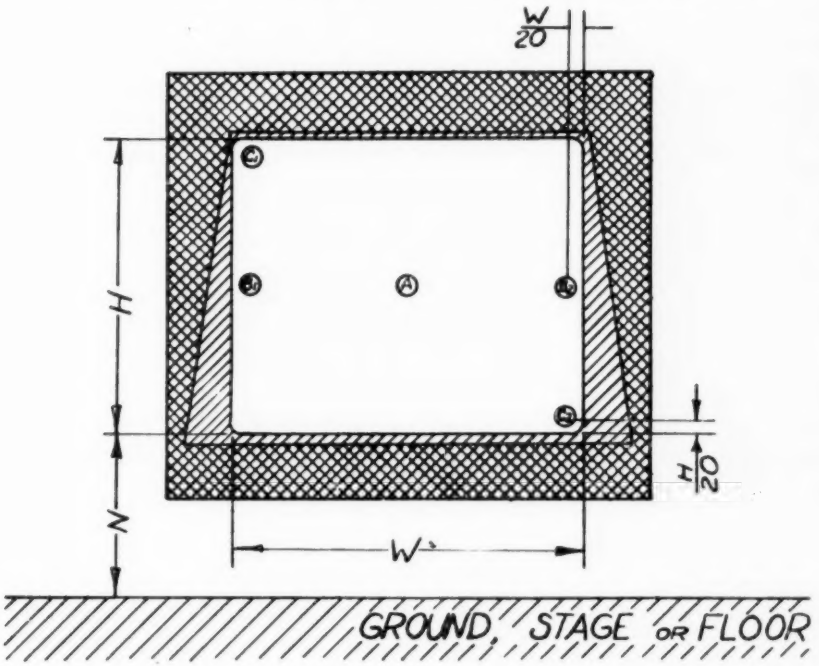
Notes

* This meter is one of the most simple for control of screen brightness. It would be desirable to have this an inexpensive instrument available in all the better projection rooms.

† Screen brightness and illumination are considered functions of the *masked area of the screen*, whereas this meter measures *total illuminated area.* Any significant difference between masked and total area must be noted.

‡ A standard projector aperture is assumed. Any departure from this standard must be noted.

§ These values of luminous flux are mean net values, integrated over a sufficient time to damp out the flicker of intermittent projection.



I. Purpose

This procedure describes practical methods for the determination of screen brightness when it is convenient to obtain data on screen illumination. Limitations on instruments commonly available make this indirect method the most generally useful for measurements in the theater.

There are three parts to the procedure: (1) Determination of illumination and illumination distribution, (2) Determination of screen reflectance, and (3) Determination of screen brightness at one selected point. Determination of brightness and brightness distribution relies upon the data of (1) plus that of either (2) or (3).

II. Measurement of Illumination

A. *Description.* This procedure gives a satisfactory measure of screen illumination for the average theater, with the projection system in good adjustment. It describes the determination of screen illumination and its variation over the screen surface, together with the calculation of total effective luminous output of the projector. It is assumed that these data will be basic for any theater evaluation of projection viewing conditions.

B. *Meter Specification.* D

C. *Data.* The projector and light source should be operated normally, with no film in the gate.

1. Measure H and W — the height and average width of the masked area.

2. Note whether there is any pronounced variation in color of illumination across the screen.*

3. Read illumination on the screen in ft-c at positions A, B_1, B_2, C_1, and C_2, using a meter that conforms to "Specification D. Illumination Meter."

4. If E_{B_1} varies from E_{B_2} by more than 50%, or E_{C_1} varies from E_{C_2} by more than 50%, the illumination is sufficiently unbalanced that calculated results will be approximate only.*

D. *Calculations.*†

5. Illuminated Screen Area: Area in square feet = S = H × W.

6. Screen Light Distribution: Side-center ratio = $R_s = \frac{E_{B_1} + E_{B_2}}{2} \times \frac{1}{E_A}$.

Corner-center ratio = $R_c = \frac{E_{C_1} + E_{C_2}}{2} \times \frac{1}{E_A}$

7. Total Screen Lumens:‡

$E_A \times 2$ =
$E_{B_1} + E_{B_2}$ =
$\frac{1}{2}(E_{C_1} + E_{C_2})$ =

Total
Weighted Average = F = $\frac{1}{5}$ (Total)
Screen Lumens = F × S

E. *Notes*

* If the light beam is decentered, the distribution is poorly chosen, or the equipment is in maladjustment, then the data will indicate how the theater was operating, but it will be difficult to draw other valid conclusions. Variations in color of screen light usually indicate that the optical system components are out of position. Unbalance, as defined in C section 4 usually indicates poor centering, in which case E_A will not be the maximum illumination, and the weighting factors for total flux will not be correct.

† If the projector has a nonstandard aperture, or if the illuminated area is significantly larger than the masked screen area, then the useful screen lumens may be appreciably less than the total projector output. Excessive masking will also tend to improve light distribution because the fall-off becomes more rapid at the edge of the aperture. Significant differences between lighted area and screen area may be expected when projection angles are steep — unless this problem is concealed by the use of a nonstandard, trapezoidal aperture.

‡ The weighting factors in section 7 recommended for estimating total screen lumens from the 5-point measurements may be corrected slightly as more data are analyzed.

III. Measurement of Reflectance

A. *Description.* This procedure will measure screen reflectance for screens which are essentially matte.* In general it is intended to permit use of less expensive and sensitive instruments, which therefore may need more light on the screen than is supplied by a projection beam — perhaps requiring an auxiliary light source up close to the screen and meter. Constancy of reflectance over the screen surface is assumed.† The data are intended for use in calculating screen brightness from screen illumination.

B. *Meter Specification.* F

C. *Data.*

1. Examine the screen for qualitative evidence of nondiffuse reflection, and of variation in reflectance over the screen surface.‡

2. Measure reflectance at one point on the screen (preferably the geometric center if convenient).

D. *Calculations.*

3. ρ = Apparent Reflectance,§ measured in 2 above.

E. *Notes*

* For matte screens which are essentially perfect diffusers, readings of the Reflectometer Specification F indicate the screen reflectance reasonably well. Because this reflectance is a constant independent of viewing angle, the value is applicable for estimating brightness as

perceived from any audience position. If the screen does not approximate a perfect diffuser, then the determination of reflectance is much more laborious.

† Screen Reflectance as herein considered is an integrated value. It is based upon a section of screen small enough to be convenient to measure, and in practice to have constant illumination, but large enough to average the perforated and nonperforated areas of the screen.

‡ Although substantially diffuse reflectance constant over the whole screen is a prerequisite and is frequently assumed (and this is consistent with most of the data from the Theater Survey) there is indication that controlled-reflection screens will become more numerous. For such screens it is essential that one determine reflectance as a polar function of viewing angle. Visual inspection or a simple check with the meter described in this Procedure will detect any wide departure from the usual reflectance pattern. Data from such screens should be clearly identified so that the results are not misinterpreted.

§ The screen property measured is more properly called "Apparent Reflectance," because it is the ratio of the brightness of the screen as seen at a given viewing angle, to the brightness of a perfect diffuser illuminated with the same incident flux. The foot-lambert unit of brightness is so defined that a perfect diffuser illuminated by a flux of 1 ft-candle has an apparent brightness in any direction of 1 ft-lambert.

Therefore

ρ = Apparent Reflectance =

$$\frac{B}{E} = \frac{\text{Brightness}}{\text{Illumination}}$$

IV. Measurement of Brightness

A. *Description.* This method is to be used when a Brightness Meter is available, of adequate sensitivity and response. Brightness is measured when the screen is illuminated by the projection light.

B. *Meter Specification.* B* or C†

C. *Data.*

1. Examine the screen for qualitative evidence of nondiffuse reflection and of variation in reflectance over the screen surface.‡

2. Measure Screen Brightness at one point on the screen (preferably the geometric center)† using a meter that conforms to Spec. B or Spec. C.

3. Measure Screen Illumination at the same point, within 1 min or less to minimize light fluctuations, using a meter that conforms to "Specification D. Illumination Meter."

D. *Calculations.*

4. ρ_A = Apparent Reflectance§ at A

$$\rho_A = \frac{B_A}{E_A} = \frac{\text{Brightness at A}}{\text{Illumination at A.}}$$

E. *Notes*

* If a meter of Type B is available, it would be possible to complete the measurement of brightness distribution using only this instrument and reading directly.

† Meters of Type C measure the integrated brightness over so large an area that measurements made near the screen border are frequently in error because the meter "sees" the dark border. Consequently in order to provide distribution data, the distribution of illumination (Part II) is relied upon to indicate the distribution pattern of brightness too.

‡ This procedure in this simplified form is intended only for matte screens, approximating perfect diffusers. Also see Part III, Note ‡.

§ See Part III, Note §.

V. Calculation of Brightness and Brightness Distribution

A. *Description.* This calculation is intended to give values of bare screen brightness for determining conformance to ASA Standard PH22.39-1952, for determining the side-center and corner-center brightness distributions, and for estimating the adequacy of picture viewing conditions.

B. *Prerequisites.* It will be necessary first to complete Part II and either

Part III or Part IV of this procedure.

C. *Data.*

1. Illumination at the specified points (from Part II)

E_A, E_{B_1}, E_{B_2}, E_{C_1}, and E_{C_2}

2. Apparent Reflectance (from Part III or IV)

ρ_A (or ρ_C if only this can be measured conveniently)*

D. *Calculations.*

3. B_A = Brightness of screen at A† = $\rho \times E_A$ = (Apparent Reflectance) × (Illumination at A).

4. $B_{B_1} = \rho \times E_{B_1}$, etc.

5. V_s = side-center ratio‡ = $\frac{B_{B_1} + B_{B_2}}{2} \times \frac{1}{B_A}$. V_c = corner-center ratio‡ = $\frac{B_{C1} + B_{C2}}{2} \times \frac{1}{B_A}$.

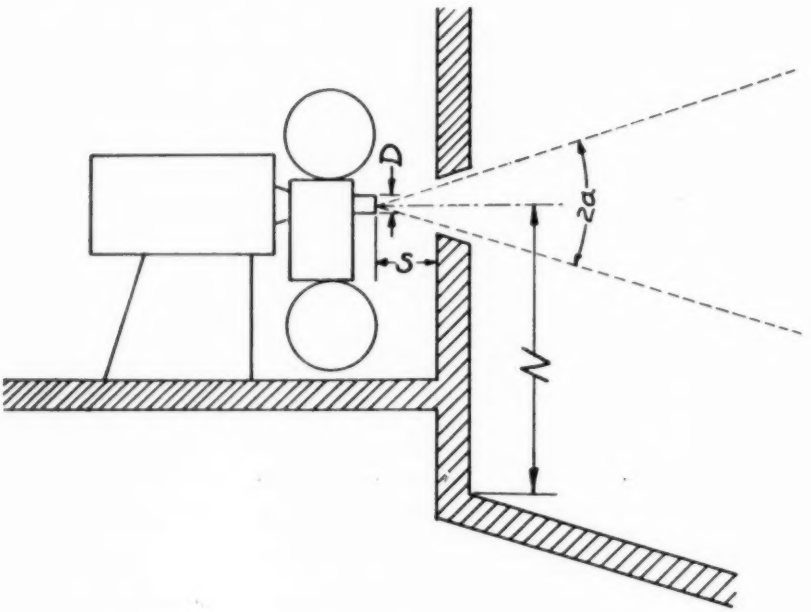
E. *Notes*

* It is assumed in this procedure that ρ = Apparent Reflectance, is constant over the whole screen surface, and is independent of viewing angle.

† This center brightness is the only quantity specified in ASA Standard for Screen Brightness PH22.39-1952.

‡ It will be apparent that since the screen is assumed to be a perfect diffuser, these brightness ratios will be numerically equal to the illumination ratios calculated in Part II.

Recommended Practice for the Measurement of Luminous Flux



I. Purpose

This procedure describes a method of determining the total luminous output of the projector when it is inconvenient or undesirable to obtain data at the screen (cf. "Recommended Practice for the Determination of Bare-Screen Brightness"). From the measurement of Luminous Flux it is possible to check projector alignment and operation. With certain assumptions it is also possible to estimate screen brightness. This procedure will be most useful for projector adjustment and repair, and for checking the constancy of projector performance.

In some of the larger outdoor theaters and in a few indoor theaters, screen size and construction makes it extremely difficult to support a brightness or illumination measuring cell at many of the specified locations at the screen surface (cf. Instruments of Spec. C or D). This procedure therefore fills the need of supplying some "screen brightness" data when otherwise none would be available. Measurements are made with the projector and light source operated normally, except that no film is run through the gate.

Measurements of Luminous Flux can be made with meters of Specification G or H. When estimates of screen brightness are desired, measurements should be made with the Type G; since meters of Specification H do not indicate the variation in illumination intensity over the screen area, and only average illumination can be determined. To determine conformance to the Screen Brightness Standard ASA PH22.39-1952, center brightness must be known.

II. Measurement of Illumination: Meter Type G

A. *Data.*

1. Focus the projector normally on the screen. Examine screen for qualitative evidence of nonsymmetrical lighting, abnormal distribution, or variation in color of illumination.*

2. Measure total luminous flux leaving the projection lens.

3. Insert masks in projection aperture† and measure relative illumination to each of the 5 locations included in "Recommended Practice for the Determination of Bare-Screen Brightness."

B. *Calculations.*

4. *Total Screen Lumens:* read directly from 2 above.

5. *Center Screen Illumination:* read directly from 3 above with the mask corresponding to position "A."

6. *Screen Light Distribution:* calculated from the readings of 3 above.

$$\text{Side-Center Ratio } R_s = \frac{E_{B_1} + E_{B_2}}{2} \times \frac{1}{E_A}$$

$$\text{Corner-Center Ratio } R_c = \frac{E_{C_1} + E_{C_2}}{2} \times \frac{1}{E_A}$$

7. *Average Screen Illumination:* calculated from the readings of 3 above, using the weighting factors given in Part II, Section D-7, of "Recommended Practice for the Determination of Bare-Screen Brightness.

8. *Screen Brightness*‡: Brightness corresponding to the illumination values of 5, 6, and 7 above can be calculated by the method of Part V "Recommended Practice for the Determination of Bare-Screen Brightness" providing that reflectance has been measured or is known.

C. *Notes*

* This procedure will determine satisfactorily the total luminous output of the projector. If the system is in good adjustment this value has significance. If the light beam is decentered, the distribution is poorly chosen, or the equipment is in maladjustment, however, the results will be difficult to interpret. Nonsymmetrical lighting is wasteful of light, poorly chosen distribution impairs either total illumination or picture quality, color variations in illumination usually result from poor positioning of the optical system components.

† These measurements relate to the standard projector aperture. If the aperture is nonstandard, or if the illuminated area overlaps the screen border significantly, these data on total output may not reflect properly the useful light directed to the picture area of the screen.

‡ Inasmuch as the present Screen Brightness Standard specifies only the brightness as the center of the screen without mention of distribution, it will be necessary to calculate center brightness to determine conformance to standards. Average brightness has not been standardized.

III. Measurement of Luminous Flux: Meter Type H

A. *Data.*

1. Focus the projector normally on the screen. Examine screen for qualitative evidence of nonsymmetrical lighting or abnormal distribution.*

2. Measure total luminous flux leaving the projection lens.†

B. *Calculations.*

3. Total Screen Lumens: are read directly.

4. Average Screen Illumination: can be calculated if the illuminated area is measured.

5. Average Screen Brightness‡ corresponding to the average illumination of 4 above, can be calculated by the method of Part V "Recommended Practice for the Determination of Bare-Screen Brightness" providing that reflectance has been measured or is known.

C. *Notes*

* This procedure will determine satisfactorily the total luminous output of the projector. If the system is in good adjustment this value has significance. If the light beam is decentered, the distribution is poorly chosen, or the equipment is in maladjustment, however, the results will be difficult to interpret. Nonsymmetrical lighting is wasteful of light, poorly chosen distribution impairs either total illumination or picture quality, color variations in illumination usually result from poor positioning of the optical system components.

† These measurements relate to the standard projector aperture. If the aperture is nonstandard, or if the illuminated area overlaps the screen border significantly, these data on total output may not reflect properly the useful light directed to the picture area of the screen.

‡ Inasmuch as the present Screen Brightness Standard specifies only the brightness at the center of the screen without mention of distribution, it will be necessary to calculate center brightness to determine conformance to standards. Average brightness has not been standardized.

References

1. F. B. Berger, "Characteristics of motion picture and television screens," *Jour. SMPTE, 55:* 131–146, Aug. 1950.
2. Ellis W. D'Arcy and Gerhard Lessman, "Objective evaluation of projection screens," presented on April 22, 1952, at the Society's Convention at Chicago.
3. W. W. Lozier, "Report of the Screen Brightness Committee," *Jour. SMPTE, 57:* 238–246, Sept. 1951.
4. F. J. Kolb, Jr., "The scientific basis for establishing brightness of motion picture screens — a discussion of screen brightness," *Jour. SMPTE, 51:* 433–442, Apr. 1951.

Proposed Revision, PH22.58 and PH22.59 Apertures for 35mm Projectors and Cameras

PROPOSED REVISIONS of two American Standards are published on the following pages for three-month trial and criticism. All comments should be sent to Henry Kogel, SMPTE Staff Engineer, prior to January 15, 1954. If no further revisions are recommended, the two proposals will then be submitted to ASA Sectional Committee PH22 for further processing as American Standards.

While these two standards on projector and camera apertures, PH22.58 and PH22.59, deal only with the old 1.33 aspect ratio, it is nonetheless important that they be kept on the books and brought up to date because large segments of the motion-picture industry, both at home and abroad, are still making and projecting motion pictures in accord with these standards. In addition all motion pictures made for television are based upon them.

An earlier proposed revision of the projector aperture standard was published for trial and comment in the June 1953 *Journal* and it is instructive to repeat the accompanying explanatory introduction.

"In reviewing PH22.58, the Film Projection Practice Committee came to the conclusion that the camera centerline should be deleted as well as dimension H which specified the 6-mil differential between camera and projector centerlines. The 6-mil differential was originally inserted to make allowance for film shrinkage so that the release print, after shrinking its normal amount, would have the image centered in the projector aperture. The decrease in the shrinkage characteristic of film eliminates the need for this differential, and now permits the use of the projector aperture centerline for both the projector and camera. In addition, the corner radius has been decreased to be in accord with present practice of essentially square corners."

It is obvious that camera and projector aperture standards are completely interdependent and the two should have been processed simultaneously. Had this been done, the values of E and F in both standards would probably have been modified by the amount of the shift in the camera aperture centerline. On the authorization of Henry Hood and Glenn Dimmick, Engineering Vice-President and Standards Committee Chairman, respectively, these changes have now been incorporated in both draft revisions.

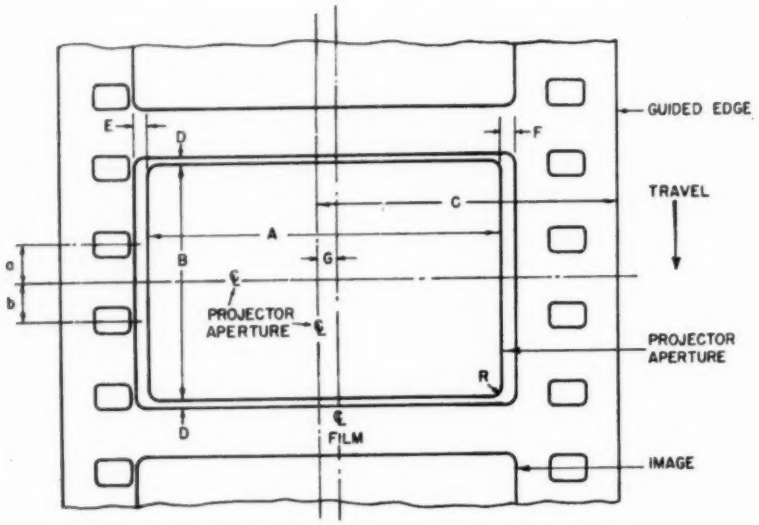
It should be noted in this first publication of PH22.59, as revised from the earlier Z22.59-1947, that the values of C, E and F have been altered by 6 mils and that the title has been slightly modified. The value of dimension F, of course, affects the space available for the sound record, as specified in American Standard Z22.40-1950. The possibility of conflict on this score should be given consideration in your critical review of these standards.—*H.K.*

Proposed American Standard

Aperture for 35mm Sound Motion-Picture Projectors

Second Draft

PH22.58
Revision of Z22.58–1947



Dimension	Inches	Millimeters
A	0.825 ± 0.002	20.95 ± 0.05
B	0.600 ± 0.002	15.25 ± 0.05
C	0.738 ± 0.002	18.74 ± 0.05
D	0.0155	0.394
E	0.022	0.56
F	0.021	0.53
G	0.049	1.24
R	Not > 0.005	Not > 0.13
a = b = ½ longitudinal perforation pitch.		

These dimensions and locations are shown relative to unshrunk raw stock.

Note: The aperture dimensions given result in a screen picture having a height-to-width ratio of 3 to 4 when the projection angle is 14 degrees.

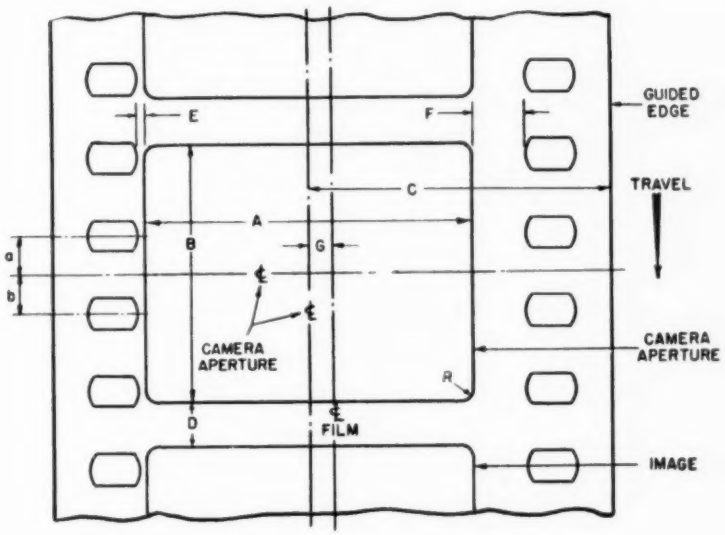
NOT APPROVED

Proposed American Standard

Aperture for 35mm Sound Motion-Picture Cameras

First Draft

PH22.59
Revision of Z22.59-1947



Dimension	Inches	Millimeters
A	0.868 ± 0.002	22.05 ± 0.05
B	0.631 ± 0.002	16.03 ± 0.05
C	0.738 ± 0.002	18.75 ± 0.05
D	0.117	2.97
E	0.016	0.38
F	0.115	2.92
G	0.049	1.24
R	0.03 Approx.	0.76 Approx.
a = b = ½ longitudinal perforation pitch.		

These dimensions and locations are shown relative to unshrunk raw stock.

Note: The aperture dimensions given in combination with an 0.600 × 0.825 in. (15.25 × 20.95 mm) projector aperture result in a screen picture having a height-to-width ratio of 3 to 4 when the projection angle is 14 degrees.

NOT APPROVED

Engineering Activities

American Standards on Photographic Rolls and Sheets

Below are listed the numbers and titles of recently approved American Standards in the field of still photography. These may be ordered from the American Standards Association, 70 E. 45 St., New York 17, N.Y. Additional listings of such standards will be published in the *Journal* from time to time, as they are made available, as a service to those readers who maintain an active interest in still, as well as motion-picture, photography.

"Photographic Paper Rolls," PH1.11-1953. (Revision of Z38.1.5-1943 and Partial Revision of Z38.1.6-1943)

"Photographic Paper Sheets," PH1.12-1953. (Revision of Z38.1.43-1947 and Partial Revision of Z38.1.6-1943)

British Standards

Three British Standards and one draft standard have been received at the Society Headquarters and are listed below.

BS 586:1953. Photo-Electric Cells of the Emission Type for Sound Film Apparatus.

BS 1404:1953. Screen Luminance (Brightness) for the Projection of 35Mm Film.

BS 1988:1953. Measurement of Frequency Variation in Sound Recording and Reproduction.

CR (ACM) 3896. Draft Recommendations for Determining and Expressing the Performance of Loud Speakers by Objective Measurements.

Loan copies of the above are available upon request.—*Henry Kogel*, Staff Engineer.

Book Reviews

Principles of Color Photography

By Ralph M. Evans, W. T. Hanson, Jr., and W. Lyle Brewer. Published (1953) by John Wiley & Sons, 440 Fourth Ave., New York 16, N.Y. i-xi + 672 pp. + 21 pp. bibliography + 15 pp. index. 324 illus. 6 × 9 in. Price $11.00.

Some of the best scientific reference books have been written by research workers who suddenly have become engaged in a subject and find that no authoritative text exists to give them an overall picture of the fundamental principles of that subject. In the course of reading hundreds of original papers and slowly fitting the essential facts and concepts together, the thought occurs how much easier the task would be if a reference work were available, containing the necessary background data required for investigating the subject further.

Apparently the authors of this book experienced such thoughts, especially Evans and Hanson, who recall in the preface the need that existed in the early years of Kodachrome for an exhaustive treatment of the actual basis on which processes of color photography had been and were being developed. In 1938, three years following the introduction of 16mm Kodachrome, they began the preparation of the present text. World War II and increased responsibilities afterwards made the completion of the book difficult, and so Mr. Brewer was enlisted in 1946. Mr. Brewer spent practically full time for several years in bringing the book to its final state. This gives one an idea of the comprehensive nature of the book and a fuller understanding of the tremendous amount of effort involved in writing a book in a field where no similar one existed before.

To a very large extent the book is an organized compilation of previously published material. However, much unpublished original work is included, also. There are 18 chapters, with the following titles: Response of the Eye to Light in Simple Fields; Systems of Color Specification and Measurement; Responses to Light in Complex Fields; Visual Processes and Color Photography; Response of Photographic Materials; Color Response of Photographic Materials; Photo-

graphic Formation of the Color Image; Color Photographic Systems; Types of Dyes and Other Colorants; Optical Characteristics of Colorants in Combination; Measurement of Density; Color Sensitometry; Analyses of Color-Sensitometric Characteristics; Reproduction Characteristics of a Hypothetical Subtractive Color Process; Duplicating; Copying a Color Photograph; Color Reproduction Theory for Additive Photographic Processes; and Color Reproduction Theory for Subtractive Photographic Processes. An extensive bibliography, author index and subject index complete the book.

Mathematics is used freely throughout the text wherever the subject material is amenable to such treatment. The authors state that they attempted to word the text so that a careful study of the mathematical steps would not be required for an understanding of the principles and conclusions reached. Their attempt in this has not been too successful, in the opinion of the reviewer, but it is probably as close to success as could be expected without an extensive expansion of the present book. Perhaps if the discussions on certain subjects which have no place in the book had been eliminated, it would have been possible to give a fuller development of the mathematical steps. Chapter V, for example, on the response of photographic materials, which takes over 50 pages, is certainly out of place, and anyone qualified to read the rest of the book will ignore it. There are at least another 200 pages in the book that will be regarded as "filler" by the audience for which the book is intended.

Except for the above general criticism, the book is extremely well done. It presents a thorough analysis of the problems involved in color reproduction theory and shows to what extent practical processes have approached ideal solutions. Color sensitometry and color densitometry are treated in a very lucid style. Interimage effects are nicely described and mathematically correlated with practice. The wealth of experimental data and the numerous computations are almost overwhelming at times. The chapters, from chapter seven through chapter eighteen, will be of greatest interest to most experienced photographic color technologists. These chapters contain the bulk of the new material presented in the book, but the going gets rough in spots if one's knowledge of determinants and matrices is rusty. There is no doubt but that this book should become a part of every technical reference library and should be owned personally by every color technologist.—*Lloyd E. Varden*, Technical Director, Pavelle Color Inc., 533 W. 57 St., New York 19, N.Y.

New Screen Techniques

Edited by Martin Quigley, Jr. Published (1953) by Quigley Publishing Co., 1270 Sixth Ave., New York 20, N.Y. 208 pp. 71 illus. 6 × 9 in. $4.50.

This potpourri of 26 illustrated articles is divided into two parts: Part I deals with the production and exhibition of stereoscopic motion pictures; Part II covers similar material in relation to the Cinerama and CinemaScope wide-screen systems.

Of the ten stereo articles in Part I, four are worthy of note: "Polaroid and 3-D Films" by William H. Ryan; "Basic Principles of 3-D Photography and Projection" by John A. Norling; "The Stereo Window" by Floyd A. Ramsdell; and "3-D in Theatres" by James Brigham. Concise, factual, they give the reader a good, basic background in stereocinematography. A fifth article, "3-D in Europe" by Frank A. Weber, a report on current stereo activity abroad, may be of interest to many since so little has been written on the subject. This reviewer took particular exception to "What Is Natural Vision" by Milton L. Gunzburg, because the article never quite got around to explain or support Natural Vision's adoption of the fixed interaxial, variable convergence system, giving over instead a great deal of effort to deride proponents of other systems.

The second half of the book has less of value to offer than the first. With the exception of "Adding Sound to Cinerama" by Hazard E. Reeves, "Sound for CinemaScope" by Lorin D. Grignon and "The Anamorphoser Story" by H. Sidney Newcomer, most of the material is devoted to general background and personalities rather than to the processes themselves.

While this collection cannot be recommended as a source of information for engineers, it may well be of topical interest to many in our industry who want to be in touch in a general nontechnical way with developments in the stereoscopic field. It must be assumed that this is the audience for which the book was intended.—*Arnold F. T. Kotis*, Stereo Consultant, 3937 49 St., Sunnyside, L.I., N.Y.

Television Advertising and Production Handbook

By Irving Settle, Norman Glenn and Associates. Published (1953) by Thomas Y. Crowell, 432 Fourth Ave., New York 16, N.Y. i–xv + 356 pp. + 109 pp. appendix + 11 pp. index. Numerous illustrations, diagrams and plates. $6.00.

By unfreezing over six hundred television channels in the VHF bands and over fourteen hundred in the UHF bands, the FCC has given impetus to the construction and operation of hundreds of new television stations in the near future. Thousands of applications will be made for construction permits and eventually hundreds will be granted with the ultimate aim of having at least one television station in every city, large or small, in the United States and its possessions. Added to this will be hundreds of firms supplying equipment, services and personnel. This opens up thousands of jobs for trained men and women in television and its associated field.

Television Advertising and Production Handbook is written and compiled to assist those interested in any phase of planning, setting up and operating a television station. The authors, Irving Settle and Norman Glenn, together with their associates, are all associated with nationally known firms engaged in operating or servicing the television industry.

All fields are covered in the handbook, from the methods of computing the cost of installation and operation of all types of stations through research, national and local selling, mail order programs, staging, producing, casting, publicity and censorship to the methods of obtaining personnel.

A sample script from one of the Armstrong Circle Theatre dramatic presentations together with the casting, set production, camera direction and cuing is included.

Two chapters, "Producing TV Film Commercials" by Rex Cox of Sarra Inc. and "Film Package Syndication for TV" by Everett Crosby of Bing Crosby Enterprises will appeal to the motion-picture producer.

This reviewer feels this book will be of interest to anyone contemplating a career in television but will have its greatest value to prospective owners, managers, agency executives, promotional managers and producers. The handbook would make an excellent text for college or extension courses in these fields.—*William K. Aughenbaugh*, 4014 St. Johns Ter., Cincinnati, Ohio.

1953–54 Motion Picture and Television Almanac

Published (1953) by Quigley Publications, 1270 Sixth Ave., New York 20, N.Y. i–l + 1056 pp. (including advt.), thumb indexed. 6 × 9 in. $5.00.

This is the twenty-fifth annual edition of this widely used reference work. Information on the television industry, which was incorporated in the volume for the first time last year, has this year been greatly expanded and revised. It appears interspersed throughout the book, wherever relevant, as well as in a separate section.

Following the Who's Who in Motion Pictures and Television section, a useful reference file of personalities in the industry, the Almanac comprises sections on:

Corporations — Detailed information on corporate make-up and officer personnel of the companies in the motion-picture industry.

Drive-Ins — A complete listing of the drive-in theaters of the United States and Canada, with pertinent information on each installation.

Television — Data on the industry, with corporation listings; a complete list of all the television stations authorized in the United States; FCC channel allocations, nationally; the leading advertising agencies; the Television Code; a listing of program material and its source; a list of station representatives, and other information.

Pictures — A detailed listing of all feature releases from 1944 to 1953; a company-by-company breakdown of pictures of the current season; foreign films in the United States; British films in the United States, and the origin of foreign films in the United States.

Award and Poll Winners — A listing of Academy Award winners through the years; the history of the "Oscar"; the various Quigley Publications Awards; awards of the SMPTE, and other film and television awards.

Services — A section which includes listings of the motion-picture exchanges in all the key cities of the country and Canada; distributors of trailers; film carriers; shorts, cartoon and newsreel producers; film laboratories; color processes; film storage vaults; raw stock and film libraries; literary and talent agencies; publicity representatives; government film bureaus.

Equipment — A listing of manufacturers and services; equipment listed by categories; supply dealers in the United States and Canada.

Motion-Picture Organizations — A detailed listing of film organizations, producer-distributor and exhibitor; guilds and unions; Variety Clubs, film clubs and miscellaneous groups.

Codes — A full text of the Motion Picture Production Code; Motion Picture Advertising Code; Television Code; listing of censorship boards in the United States; public previewing groups; motion-picture councils.

World Market — Detailed information on the film industry in various countries of the world, with market analyses.

Great Britain — A complete set of data on the industry in Great Britain, with listings of companies, trade organizations, government film departments, studios and laboratories, theater circuits and television units.

Press — Listings of motion-picture and television trade publications; film writers of the newspapers; television writers of the newspapers; fan magazines; national magazine writers; foreign press film correspondents.

Nontheatrical — A listing of producers of nontheatrical motion pictures for advertising, television, educational purposes and libraries.

New Members

The following members have been added to the Society's rolls since those last published. The designations of grades are the same as those used in the 1952 MEMBERSHIP DIRECTORY.

Honorary (**H**) Fellow (**F**) Active (**M**) Associate (**A**) Student (**S**)

Allaire, Robert J., Supervisor, 16mm Printing, U.S. Army Signal Corps. **Mail:** 142-42—56 Rd., Flushing, N.Y. (**M**)

Babits, Victor A., Professor, Electrical Engineering, Rensselaer Polytechnic Institute. **Mail:** 64—9th St., Troy, N.Y. (**M**)

Baldwin, Millard W., Jr., Television Research Engineer, Bell Telephone Laboratories, Inc., Murray Hill, N.J. (**M**)

Barnett, Sterling, Production Manager, Photographic Analysis, Inc., KTTV Studios. **Mail:** 9006 Aqueduct Ave., Sepulveda, Calif. (**M**)

Birr, R. E., Illumination Engineer, Lamp Division, General Electric Co., Application Engineering, Nela Park, Cleveland 12, Ohio. (**A**)

Brackett, Harold E., Cinematographer. **Mail:** 280 West End Ave., New York 23, N.Y. (**A**)

Bransby, John, Motion-Picture Producer, John Bransby Productions. **Mail:** Dudley Rd., Wilton, Conn. (**M**)

Bredshnyder, Vitold, Special Effects Performer, Cameraman, Anderson Elevator Co. **Mail:** 202 W. Fifth St., Perrysburg, Ohio. (**M**)

Brix, John, Motion-Picture Film Editor, Sarra, Inc. **Mail:** 5449 West Henderson St., Chicago, Ill. (**A**)

Carlson, Arvid W., Cameraman and Editor, Douglas Productions. **Mail:** 213 West Fremont St., Arlington Heights, Ill. (**A**)

Chase, Richard Alan, Film Editor, WNHC Elm City Broadcasting Co. **Mail:** 70 Howe St., c/o Clarkson, Apt. 209, New Haven, Conn. (**A**)

Clark, Alex L., President, Alex L. Clark Limited and Magnecord Canada Limited, 2914 Bloor St., West Toronto 18, Ontario, Canada. (**A**)

Cogan, Jack A., Product Engineer, Eastman Kodak Co. **Mail:** 113 Nantucket Rd., Rochester 13, N.Y. (**M**)

Collier, William W., Chief Aviation Photographer's Mate, U.S. Navy. **Mail:** 422 West Jackson Ave., Warrinton, Fla. **(A)**

Cooney, Stuart M., Jr., Television Staff Engineer, Springfield Television Co. **Mail:** 40 High St., Apt. 44, Springfield 5, Mass. **(A)**

Daniels, William H., Director of Photography, Universal-International Pictures. **Mail:** 10307 Lorenzo Dr., Los Angeles 64, Calif. **(M)**

Dreyer, John F., President, Polacoat, Inc., and Depth Viewers, Inc., 9750 Conklin Rd., Blue Ash, Ohio. **(M)**

Edgerton, Richard O., Section Supervisor, Professional 35mm Color Film, Eastman Kodak Co. **Mail:** 104 Alameda St., Rochester 13, N.Y. **(A)**

Embacher, Hans R., Chief Mechanical Engineer, Optomechanisms, Inc., 216 East Second St., Mineola, Long Island, N.Y. **(M)**

Fason, Jack, Chief, Medical Illustration Laboratory, Veterans Administration Hospital. **Mail:** P.O. Box 8785, Denver, Colo. **(M)**

Felton, Elmer, Coordinator, Teacher, Phoenix Union High Schools and College District. **Mail:** 1123 West Parkview Dr., Phoenix, Ariz. **(M)**

Ferguson, Frank E., Film Production Specialist, Audio-Visual Center, Syracuse University, Syracuse, N.Y. **(A)**

Fink, Donald G., Director of Research, Philco Corp. **Mail:** 845 Dale Rd., Meadowbrook, Pa. **(M)**

Fleck, Lucile H., President, Vacuumate Corp., 446 W. 43 St., New York, N.Y. **(A)**

Gardner, Loris M., Photographic Supervisor, Los Alamos Scientific Laboratory, Box 1663, Los Alamos, N.M. **(M)**

George, Robert Leland, Design Engineer, Berndt-Bach, Inc. **Mail:** 5246 Bindewald Rd., Torrance, Calif. **(M)**

Gevatoff, Sam, Motion-Picture Timer, Signal Corps Photo Center. **Mail:** 1484 Watson Ave., Bronx, N.Y. **(M)**

Gobrecht, Robert L., Cameraman, Director, Audio-Visual Center, Syracuse University. **Mail:** Technical Corporation ADM, APO 205, c/o Postmaster, New York, N.Y. **(A)**

Goldwasser, Samuel R., Chemist, Color Laboratory, Signal Corps Pictorial Center. **Mail:** 2285 Ocean Ave., Brooklyn 29, N.Y. **(A)**

Gregor, William, Camera Technician, Radio Optical Research Co., 617 North La Peer Dr., West Hollywood, Calif. **(M)**

Grodewald, Herbert H., Partner, Technical Film Studio. **Mail:** 147-17 Cherry Ave., Flushing, N.Y. **(M)**

Groshan, Robert M., Professional Cinemaphotographer. **Mail:** 2422 Tuscarawas St., West, Canton, Ohio. **(M)**

Hackett, R., Supervisor, Audio-Visual Education, York Township Board of Education. **Mail:** 57 Eagle Rd., Toronto, Ontario, Canada. **(A)**

Hall, Don, Jr., Production Assistant, Mercury International Pictures, 6611 Santa Monica Blvd., Hollywood 38, Calif. **(M)**

Hamid, Mohammed, Engineer, Photographer, Embassy of Pakistan, 2201 R St., N.W., Washington, D.C. **(A)**

Hayes, John Edmund, Professional Engineer, Canadian Broadcasting Corp., P.O. Box 6000, Montreal, Quebec, Canada. **(M)**

Hecht, William, Product Engineer, International Projector Corp. **Mail:** 29 South Munn Ave., East Orange, N.J. **(M)**

Heller, Herman S., Owner, Manager, Herman S. Heller and Associates, 8414 West Third St., Los Angeles 48, Calif. **(M)**

Hochman, Alan, Photographer's Assistant, Walter Engel Studios. **Mail:** 3240 Henry Hudson Parkway, Riverdale, N.Y. **(A)**

Hogan, John V. L., President, Consulting Engineer, Hogan Laboratories, Inc. **Mail:** 239 Greenway South, Forest Hills 75, Long Island, N.Y. **(M)**

Hsu, James, Producer, President, Crown Cinema Corp. **Mail:** 33 Piccadilly Rd., Great Neck, N.Y. **(A)**

Ianuzzi, Anthony Pete, Mechanical Engineer, Myerberg Productions, Inc., 216 E. Second St., New York, N.Y. **(A)**

Iserman, Milton L., Printer, General Film Laboratories Corp. **Mail:** 6916 Bertrand Ave., Reseda, Calif. **(A)**

Iwabuchi, Kiichi, Chief Engineer, Toho Film Co. **Mail:** 813 Unanecho Setagayaku, Tokyo, Japan. **(M)**

Jabroff, Charles, Photographic Engineer, Signal Corps. **Mail:** 258 Bath Ave., Long Branch, N.J. **(A)**

Johnson, Herbert H., Jr., Process Chemist, Photo Products Dept., E. I. du Pont de Nemours & Co. **Mail:** 82 Kemp Ave., Fair Haven, N.J. **(M)**

Johnstone, James R., Manager, Carbon Product Sales, National Carbon Co., 30 E. 42 St., New York 17, N.Y. **(M)**

Jones, Daniel J., Development Engineer, Eastman Kodak Co. **Mail:** 512 Daytona Ave., Webster, N.Y. **(A)**

Juett, Francis Edward, Processing Manager, George Humphries & Co., Ltd. **Mail:** 3 Oakwood Ave., Boreham Wood, Herts, England. **(A)**

Kellman, Louis W., Motion-Picture Producer. **Mail:** 1729 31 Sansom St., Philadelphia, Pa. **(M)**

Kennedy, Richard F., Soundman, Business Manager, Audio-Visual Center, Syracuse University. **Mail:** c/o T.C.I., U.S. Embassy, Tehran, Iran. **(A)**

Knoblock, George C., Supervisor, Film Assembly and Inspection, Wilding Picture Productions, Inc. **Mail:** 1529 West Roscoe St., Chicago 13, Ill. **(A)**

Leichman, Alfred C., Theatre Ticket Clerk, Mutual Theatre Ticket Co. **Mail:** 129 W. 48 St., c/o Bristol, New York 36, N.Y. (A)

Levine, John H., Motion-Picture Projectionist, Sound Technician, Poli—New England Theatres, Inc. **Mail:** 9 Kelley Square, Worcester 4, Mass. (M)

Lundy, Curtis S., Service Inspector, Altec Service Corp. **Mail:** P.O. Box 1386, Lansing 4, Mich. (A)

Mahnke, Carl F., Jr., Production Manager, Carl F. Mahnke Productions, 215 East Third St., Des Moines 9, Iowa. (A)

Malkames, Karl, Newsreel Cameraman, Warner Brothers Pathe News Inc. **Mail:** 22 Benedict Rd., Fulton Park, White Plains, N.Y. (M)

Manning, David D., Film Director, WHAM-TV; President, General Manager, Tele-Visuals, Inc. **Mail:** 42 Del Rio Dr., Rochester 18, N.Y. (M)

Marshall, Eldon L., Cinematographer, Hughes Sound Films. **Mail:** 2111 Poplar, Denver 7, Colo. (M)

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Matzko, Gustave, Supervisor, Motion-Picture Laboratory Maintenance, U.S. Army Signal Corps. **Mail:** 126 Bennett Ave., Yonkers, N.Y. (A)

Miller, C. David, Assistant Supervisor in Engineering Research, Battelle Memorial Institute. **Mail:** 1268 West Second Ave., Columbus 12, Ohio. (M)

Moone, Levi E., Motion-Picture Cameraman and Laboratory Supervisor, U.S. Government. **Mail:** 5557 Livingston Rd., Washington, D.C. (M)

Muehlstein, Daniel F., Photographic Engineer, Eastman Kodak Co., 1712 South Prairie Ave., Chicago 16, Ill. (M)

Nallan, William J., Jr., Sound Engineer, Fox Movietone. **Mail:** 2 Tree La., Wantagh, Long Island, N.Y. (M)

Nelson, Edward J., Engineer, Ballantyne Co., 1712 Jackson, Omaha, Nebr. (M)

Neumer, A. E., Optical Engineer, Bausch & Lomb Optical Co., 635 St. Paul St., Rochester 2, N.Y. (M)

Noble, James J., Engineer, Altec Lansing Corp., 9356 Santa Monica Blvd., Beverly Hills, Calif. (M)

Peed, Allie C., Jr., Technical Editor, Eastman Kodak Co., Sales Service Division, 343 State St., Rochester, N.Y. (M)

Peirano, Augusto Roca, Motion-Picture Laboratory, Instituto Cinematografico Boliviano, Indaburo 212, Postal Box 2368, La Paz, Bolivia, S.A. (M)

Perry, Charles A., Motion-Picture Director Pilot Productions, Inc. **Mail:** 1804 McCormick Blvd., Evanston, Ill. (M)

Peters, Hugh Griffith, Producer, President, Peters and Co., 227 West Boscawen St., Winchester, Va. (M)

Pomeroy, Robert R., General Engineer, U.S. Navy Special Devices Center. **Mail:** 51 Mackey Ave., Port Washington, N.Y. (A)

Price, R. Lee, Senior Electronic Engineer, Magnecord, Inc. **Mail:** 756 South Highland Ave., Barrington, Ill. (M)

Randon, Lee, Film Director, Producer, Henri, Hurst & McDonald, Inc. **Mail:** 406 Dewey Ave., Evanston, Ill. (M)

Ray, George A., Jr., Mechanical and Electrical Engineer, Motiograph, Inc., 4431 W. Lake St., Chicago 24, Ill. (M)

Riefberg, Morton L., Chemist, U.S. Army Signal Corps. **Mail:** 205 Sea Breeze Ave., Brooklyn 24, N.Y. (A)

Roat, Edward S., Chemist, Eastman Kodak Co. **Mail:** 83 Gorsline St., Rochester 13, N.Y. (A)

Rodriguez S., Abelardo, Distributor, FOTO Mexico SA DE CV, Avenue CuauhTemoc 130, Mexico, D.F., Mexico (A)

Runde, Fred J., Jr., Motion-Picture Cameraman, E. I. du Pont de Nemours & Co. **Mail:** 2241 Cumming Rd., Augusta, Ga. (A)

Salzberg, Emmett R., Motion-Picture Film Processing, Precision Film Laboratories, Inc. **Mail:** 514 West 110 St., New York 25, N.Y. (A)

Schartel, Egon, Film Technician, Quality Control, Consolidated Film Industries. **Mail:** 7 Hazlitt Ave., Fort Lee, N.J. (M)

Schlanger, Sam, Engineer, Camera Equipment Co. **Mail:** 44 Forest Rd., Valley Stream, Long Island, N.Y. (A)

Schubert, Alvin E., General Superintendent, Development and Engineering, Eastman Kodak Co., 343 State St., Rochester, N.Y. (M)

Seda, Anton C., Engineer, De Vry Corp. **Mail:** 129 North Charles Ave., Villa Park, Ill. (A)

DECEASED

Russey, Elwood M., Director of Photography, Byron, Inc. **Mail:** Box 45, RFD #1, Vienna, Va. (M)

Serrurier, Mark, Owner, Moviola Manufacturing Co., 1451 Gordon St., Hollywood 28, Calif. (M)

SMPTE Officers and Committees: The roster of Society Officers and the Committee Chairmen and Members were published in the April 1952 *Journal*.

Employment Service

These notices are published for the service of the membership and the field. They are inserted for three months, and there is no charge to the member. The Society's address cannot be used for replies.

Positions Wanted

Experienced motion-picture production man desires connection with film company as producer-director or production manager. During past 12 yrs. experience includes directing, photographing, editing, recording and processing half-million feet finished film, including educational films, industrials, TV spots, package shows for TV and experimental films. University graduate, married, twenty-nine years old; good references. Locate anywhere continental U.S. Write Victor Duncan, 8715 Rexford Drive, Dallas 9, Tex.

Film Production/Use: Experienced in writing, directing, editing, photography; currently in charge of public relations, sales and training film production for industrial organization. Solid film and TV background, capable administrator, creative ability, degree. References and résumé upon request. Write FPF, Room 704, 342 Madison Ave., New York 17, N.Y.

Engineer, B.M.E.: Creative designs, product improvement. Photographic and electronic-mechanical fields. Cameras (film, image-orthicon and iconoscope TV cameras), color film processing, production tooling, radar. Simple constructions, pleasing appearance. Special product or production blueprints. Write J. Rafalow, Selden, N.Y.

Meetings

Theatre Equipment and Supply Manufacturers' Association Convention (in conjunction with Theatre Equipment Dealers' Association and Theatre Owners of America), Oct. 31–Nov. 4, Conrad Hilton Hotel, Chicago, Ill.

Theatre Owners of America, Annual Convention and Trade Show, Nov. 1–5, Chicago, Ill.

National Electrical Manufacturers Association, Nov. 9–12, Haddon Hall Hotel, Atlantic City, N.J.

Society of Motion Picture and Television Engineers, Central Section Meeting, Nov. 12 (tentative), Chicago Ill.

The American Society of Mechanical Engineers, Annual Meeting, Nov. 29–Dec. 4, Statler Hotel, N.Y.

Society of Motion Picture and Television Engineers, Central Section Meeting, Dec. 10 (tentative), Chicago, Ill.

American Institute of Chemical Engineers, Annual Meeting, Dec. 13–16, St. Louis, Mo.

American Institute of Electrical Engineers, Winter General Meeting, Jan. 18–22, 1954, New York

National Electrical Manufacturers Assn., Mar. 8–11, 1954, Edgewater Beach Hotel, Chicago, Ill.

Radio Engineering Show and I.R.E. National Convention, Mar. 22–25, 1954, Hotel Waldorf Astoria, New York

Optical Society of America, Mar. 25–27, 1954, New York

75th Semiannual Convention of the SMPTE, May 3–7, 1954, Hotel Statler, Washington

American Institute of Electrical Engineers, Summer General Meeting, June 21–25, 1954, Los Angeles, Calif.

Acoustical Society of America, June 22–26, 1954, Hotel Statler, New York

76th Semiannual Convention of the SMPTE, Oct. 18–22, 1954 (next year), Ambassador Hotel, Los Angeles

77th Semiannual Convention of the SMPTE, Apr. 17–22, 1955, Drake Hotel, Chicago

78th Semiannual Convention of the SMPTE, Oct. 3–7, 1955, Lake Placid Club, Essex County, N.Y.

Society of Motion Picture and Television Engineers

40 West 40th Street, New York 18, N. Y., Tel. LOngacre 5-0172
Boyce Nemec, *Executive Secretary*

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A. G. Jensen, Bell Telephone Labs., Inc., Murray Hill, N. J.

1953

C. E. Heppberger, 231 N. Mill, Naperville, Ill.
William H. Offenhauser, Jr., River St. and Charles Pl., New Canaan, Conn.
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1953–1954

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Gordon A. Chambers, 343 State St., Rochester 4, N. Y.
L. M. Dearing, Drawer 791, Hollywood 28, Calif.
William A. Mueller, 4000 W. Olive Ave., Burbank, Calif.
Charles L. Townsend, 49 Hillcrest Dr., Dumont, N. J.
Malcolm G. Townsley, 7100 McCormick Rd., Chicago 45, Ill.

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Reeves Sound Studios, Inc.
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SRT Television Studios
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Titra Film Laboratories, Inc.
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Westinghouse Electric Corporation
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Wilding Picture Productions, Inc.
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